ELECTRICITY METERS

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ELECTRICITY METERS.

ELECTRICITY METERS:

A Treatise

ON

THE GENERAL PRINCIPLES, CONSTRUCTION, AND TESTING
OF CONTINUOUS CURRENT AND ALTERNATING
CURRENT METERS, FOR THE USE OF
ELECTRICAL ENGINEERS
AND STUDENTS.

BY

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PREFACE.

Although the electricity meter forms the most important link in the chain connecting the supply station with the consumer, comparatively little has been written on the subject in this country. It is, therefore, hoped that the present work may supply what is wanting in this respect, and that some original matter may be found in the same, especially in connection with the limitations of three-wire meters, of single-phase meters for polyphase circuits, and the results obtained with polyphase meters incorrectly installed.

For the sake of convenience, the meters described in this book are divided into three main classes—viz., Continuous current, Induction, and Tariff meters—arranged in eight chapters, corresponding to the following eight subdivisions:—Continuous current quantity meters: Continuous current energy motor meters (without iron in the field or armature): Continuous current energy meters of different types: Continuous current meters for special purposes (battery, switchboard, and tram-car meters): Single-phase and polyphase induction meters: Tariff and prepayment meters. The general principles involved are explained in three separate chapters, which precede the descriptions of the meters belonging to the three main classes as stated above.

As the proper working of a meter depends on its mechanical as well as its electrical design, a special chapter is added in which the more important mechanical features of meter construction are pointed out, only the electrical details being given in the actual descriptions of the various types. A chapter on Testing, and an introductory chapter containing a few remarks relating to meters in general, are also included.

After careful consideration, it was not deemed necessary to include an historical survey of the evolution of the electricity meter. The general design of electricity meters is at the present day fairly well established, the improvements being more a matter of detail and mainly of a mechanical nature, so that no purpose is served by giving descriptions of obsolete forms of meters, however ingenious their construction and interesting from a purely historical standpoint. With the exception of those meters which form the basis of present-day practice, the designs were on lines which are no longer followed.

The main difficulty in writing a book of this description is the well-nigh impossibility of keeping absolutely up to date. The author has, however,

endeavoured to embody, as far as possible, the latest improvements in the descriptions, and to include only those meters which are in commercial use in this country, on the Continent, and in America. It is not pretended that the list of such meters has been in any way exhausted, but it is trusted that a sufficient number of the more important types has been given to enable the reader to become conversant with the methods adopted to obtain a reliable and accurate commercial meter for different purposes.

No pains have been spared to make each chapter as comprehensive and complete as practicable within the scope of the book, and to separate the mathematical principles from the purely descriptive matter. The latter is not possible, however, in treating polyphase meters.

Special attention has been devoted to the detailed proofs of the power absorbed in a polyphase circuit, as it is not easy to deduce from the instantaneous values the form of the equation for the power absorbed when the values of the currents and pressures are those actually measured.

In conclusion, the author begs to thank the numerous manufacturers and engineers, both here and abroad, who kindly supplied him with information, drawings and blocks, and, in many cases, submitted samples of meters for inspection and testing.

H. G. SOLOMON.

5, Victoria Street,
Westminster, S.W., *January* 1906.

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ELECTRICITY METERS.

CHAPTER I.

INTRODUCTORY AND GENERAL REMARKS.

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Function of an Electricity Meter.—When a commodity is supplied to consumers for illuminating, heating, power, or other domestic purposes, it is necessary to accurately determine the amount of the commodity so used, and for this purpose measuring instruments, called meters, are installed on the consumers' premises. In the case of an electricity supply the commodity is electrical energy, and the meter is then termed an electricity meter, the function of which is to register the electrical energy which is used in a given time in any circuit in which flows a current of electricity. The meter does not necessarily measure electrical energy direct; it measures either this electrical magnitude or electrical quantity.

In either case, however, it registers in terms of the supply unit of electrical energy. In other words, the difference between two readings of the scale, dials, or counter of the registering part of the meter gives, within certain error limits, the amount of the electrical energy consumed in a given period in terms of the supply unit, generally without the use of a multiplier, the two readings being taken at the commencement and termination of the period under consideration. The supply unit in this country is the Board of Trade (B.O.T.) unit, one B.O.T. unit being equal to one kilowatt-hour, or 1000 watt-hours. In France the hectowatt-hour is largely used (one hectowatt-hour equals 100 watt-hours), and in Germany and America the unit is the kilowatt-hour.

Classifications of Meters.—According to the electrical magnitude to be measured, the instrument is termed an energy meter or a quantity meter.

An energy meter is more usually spoken of as a watt-hour, and a quantity meter as an ampere-hour meter.

As the unit of electrical energy in this country with reference to meter registrations is the kilowatt-hour, the term '*kilowatt-hour* meter' is preferable to the one '*watt-hour* meter,' commonly used.

The operation of an electricity meter depends on one or other of the well-

known thermal, chemical, and electro-magnetic properties of a current flowing in a conductor, and meters may be classified accordingly as thermal, electrolytic, and electro-magnetic meters. The thermal principle is, however, only used in meters for specific purposes, such as maximum demand indicators. An electrolytic meter is essentially an ampere-hour meter, and, from the nature of electrolytic action, can only be used for direct currents. Electro-magnetic meters may be variously divided into motor meters, in which a continuous rotation of the moving element of the meter is produced; meters with intermittent integration; clock meters, in which the pendulum of a clock is acted upon electro-magnetically; and oscillating meters, in which an oscillatory motion is produced instead of one of rotation. In general, electro-magnetic meters may be used both on continuous and alternating current supply networks, provided they contain no iron in the electro-magnetic system used in the meter to produce motion or influence motion already existing. There is, further, an important type of meter which is based on the principle of induction, and which is only applicable to alternating currents. Electro-magnetic meters may measure ampere-hours or watt-hours, but induction meters, as a general rule, measure energy only.

Although more meters based on the principle of intermittent integration have been devised than any other type, they are not used at the present day.

For this reason they will not be described, with the exception of the intermittent meter manufactured by the Siemens-Schuckert Werke, who, however, supply this type mainly for special work, as a battery or switchboard meter. A description of it has been included in Chapter VI., dealing with continuous current meters for the registration of the outputs of lighting, power, and traction systems, the charge and discharge of batteries, and the energy used on tram-cars. The intermittent principle is used in the Merz maximum demand indicator and the Aron maximum demand instrument, which belong to the special class of tariff meters described in Chapter XII. An intermittent meter consists usually of any type of ammeter or wattmeter in combination with a clockwork mechanism, which integrates at intervals the deflections of the ammeter or wattmeter.

With reference to the system of charging, meters may be distinguished as maximum demand indicators, two-rate, hour, and, finally, prepayment or automatic slot meters. Hour meters are not electricity meters, *i.e.* they do not measure any electrical magnitude, but register the hours during which current flows in an installation. They are mainly used in connection with special tariff systems, and in this respect form a most important adjunct to the ordinary electricity meter. In certain cases they take the place of the latter, when the load of the circuit is constant, or approximately so, and the units consumed are then simply found by multiplying the product of the known value of the current in amperes and the pressure in volts (both supposed constant) by the number of hours, as given by the hour meter, and dividing the result by 1000. An hour meter consists usually of a balance wheel clock with an integrating dial. The clock can only go when the balance wheel is freed on the passage of a current, and it stops when the current is interrupted.

Importance of Meters.—The whole revenue of an electricity supply company or corporation, derived from the sale of electrical energy, is dependent on the use of electricity meters of some type or other. The great importance of the meter will be at once manifest, not only as regards its effect on the revenue of the supply company, but also from the point of view of the

consumer, who by its aid can at any moment ascertain how many units he has taken, and by multiplying this amount by the rate per unit, arrive at the cost of his electricity consumption. The meters installed in an electricity station enable the total energy generated to be accurately ascertained, from which the losses of the particular system are easily deduced. It is not sufficient to use meters on the main bus-bars only, but each feeder, whether supplying current for lighting, power, or traction, should be provided with its own electricity meter. Moreover, the feeder meters in the station should be comparable with those on the circuits controlled, *i.e.* they should all measure the same electrical magnitude. The sum of the readings in units of the house-service meters represents the total energy sold, whatever the system. The difference between the sum of the feeder meter readings and this total is taken to represent the losses which occur. When the supply is a continuous current one, at approximately constant pressure, ampere-hour meters are very extensively used. In this case, if the feeder meters measure watt-hours and the house-service meters measure electrical quantity but register in units, then this difference will not represent the true losses. Whatever the system, only energy meters should be used on the bus-bars, or in the generator circuits; the feeder meter should also be an energy meter, except in those cases where the circuits controlled by the feeder are supplied with ampere-hour meters, and then two meters in series should be used, the one measuring watt-hours and the other ampere-hours. It is most essential to be able to accurately determine the ratio of the units generated to the units sold, and this can only be satisfactorily ascertained by the aid of meters. Moreover, too many of these measuring instruments cannot be used, and their readings should be systematically taken and recorded.

Some Requisites of a Meter.—An electricity meter is essentially a commercial apparatus, and is used by every station in large quantities. It has to be capable of often standing comparatively rough treatment, and at the same time must possess the accuracy of a laboratory instrument. The most important of the many requisites of a good commercial electricity meter are—accuracy; permanency of calibration; reliability of working, whatever the nature and magnitude of the load; low internal losses; independence of temperature variations, external mechanical and magnetic disturbances; absence of creeping, *i.e.* shunt running (this latter condition applies only to watt-hour meters); low starting current; and large overload capacity.

A meter should, in addition, be light, portable, and of sound mechanical construction; the importance of the latter cannot be over-estimated. Although it is a truism that the more simple a piece of apparatus, the more reliable it is, and the less likelihood there is of its becoming deranged, this is not a sufficient reason for condemning a meter the internal arrangement of which may be complicated, provided that the greater complexity ensure greater accuracy and reliability and wider range, other conditions remaining unaltered, and the cost be not materially increased. The advantage of the same meter being suitable for both alternating and direct current is one which, at the present day, is of very little value, as continuous current commutator motor meters, without iron in the field or armature, are no longer employed for the registration of electrical energy in alternating current circuits, having been superseded by the induction motor meter. Continuous current meters of the commutator type are in many instances still working on alternating current circuits, chiefly in mixed supply systems; but even in this case, as they become faulty, they are replaced by induction meters.

In connection with induction meters, it is most important that they should be adjusted to read correctly on reasonable power factors. For ordinary practical purposes a limit should be imposed to the power factor of an alternating current circuit, and should not be lower than 0·5. It is also requisite that all current-carrying parts of a meter should be highly insulated from one another and from earth. The constant of an energy meter should not be appreciably altered by voltage fluctuations not exceeding 10 per cent. below or above the normal pressure. In the case of an alternating current energy meter the constant is, in addition, dependent on the frequency of the supply current, and it should not be appreciably altered by a ten per cent. increase or decrease in the normal periodicity of the circuit.

Whatever the merits of the electrical design of a meter, unless it be efficiently protected against mechanical damage, and from the access of dust, moisture, and insects, it will rapidly deteriorate. A meter should be as cheap as is compatible with the production of a reliable commercial instrument having a high degree of accuracy.

Accuracy.—It is most essential that a meter should be accurate, so that its registrations should represent, within reasonably small error limits, the actual units consumed. The same degree of accuracy cannot, however, be expected throughout its entire range. The accuracy obtainable depends on a number of factors, such as the electrical design, the precautions taken to eliminate as far as practicable the disturbing influences inherent to the different types, the principle of working of the meter, and the cost of manufacture. In electrolytic meters of the shunted type, the causes which adversely affect the meter are—back E.M.F., a varying ratio between the shunt and cell circuit resistances, temperature variations, the formation of crystals, and the degree of purity of the electrolyte used. In motor meters the accuracy depends on the driving torque exerted by the electrical system on the moving element, friction (solid, or both solid and liquid), temperature variations,* and the constancy of the permanent magnets used, if any.

In a motor meter, the moving element, the armature, is rotated by means of the driving torque (turning moment) exerted on it by the electrical system used, and the speed of the armature should be proportional to the power or current, according as the meter is of the watt-hour or ampere-hour type. This result is obtained by combining with the motor a suitable brake system, which in general consists of the well-known magnetic brake, the retarding torque of which is proportional to the speed. The magnetic brake consists of a disc which is rotated in the magnetic field produced by a permanent magnet. The motor meter may then be regarded as a motor generator, the generator being a magneto-dynamo with a short-circuited armature. The work the motor does consists in driving the short-circuited dynamo and the integrating mechanism, and in overcoming the frictional resistances to motion. In the case of the perfect meter the whole work done by the motor is absorbed by the dynamo, or magnetic brake, in which case a direct ratio exists between the speed and the power, or current, throughout the range of the meter.

The driving torque, which depends on the design of the electrical system used, should be made as high as possible, permitting a heavy magnetic drag, so that the work absorbed in overcoming friction is, by comparison,

* For alterations in the constants of meters due to variation in temperature, see G. W. D. Ricks, *British Association*, 1896, and Hooper, *Electrical World* (N.Y.), vol. xxi. p. 384, 1898.

negligibly small. The maximum effect is aimed at with the least expenditure of power in the meter itself, and especially as regards the waste of power in the pressure circuit of an energy meter. In a commercial meter the straight line law is not obtained on account of friction, which, moreover, is not constant, but is of a variable nature at light loads, at which its effect is mainly felt. Various devices are used to render the disturbing influence of friction negligible, and most of these are enumerated in the descriptions given of the meters. In the case of a watt-hour meter the driving torque depends on the practically constant shunt field, produced by the pressure ampere-turns of the meter, and on the main current field. There is, to a great extent, a limit imposed on the driving torque, from considerations of cost and shunt losses, and this should be borne in mind in connection with the unnecessarily high accuracies sometimes demanded in specifications, as this entails an increase in the cost of manufacture. The accuracy demanded should also not cover the whole range of the meter, but be specified between certain limits only, as this would greatly reduce the cost and simplify the meter.

Error Limits.—In specifications for electricity meters it is usual, with reference to the accuracy, to fix a definite limit of error which is not to be exceeded between definite limits of load. The most general error limit is $\pm 2\frac{1}{2}$ per cent, *i.e.* the meter is required to read correctly within $\pm 2\frac{1}{2}$ per cent. from $\frac{1}{10}$ up to full load, and its error must not exceed ± 5 per cent. at $\frac{1}{20}$ full load. In some cases, however, the dial registrations are specified to be within $\pm 2\frac{1}{2}$ per cent. of absolute accuracy at all points above $\frac{1}{20}$ full load. The latter condition is far too stringent, and should not be demanded. The size of a meter is also not always taken into account in fixing these error limits, which is obviously wrong. Higher degrees of accuracy are obtainable, but at present only at a considerable increase in the cost of the meter, and for this reason are quite unjustifiable, as anything which tends to raise the cost of supply must react adversely on the whole electrical industry. It should only be necessary for a meter to be accurate within reasonable error limits. For an interpretation of the word 'reasonable' may be cited the requirements as to accuracy at present (June 1905) made by the Board of Trade, first in respect to meters submitted to that authority for approval under clause 50 of the Electric Lighting Act, 1899; and second, to meters tested by inspectors for certification.

Meters submitted to the Board of Trade for approval of construction and pattern are examined and tested for compliance with the requirements of the Electrical Standards Laboratory.

These requirements are liable to modification from time to time to meet new developments, and in the matter of accuracy are as follows :—

Error Limits of an Electricity Meter for Board of Trade Approval.

"Meters in which the current for maximum load exceeds 3 amperes should not have an error exceeding 2 per cent (+ or −) at any point from one-tenth full load to full load. For meters in which the currents do not exceed 3 amperes, the variation from accuracy at any point from one-tenth load upwards must not exceed + or − 3 per cent."

A relaxation is, however, made by the Board of Trade with reference to the error limits for certified meters, as shown in their Rules dated 24th October 1903, an extract of which is given below :—

Rules for the Guidance of Electric Inspectors appointed by the Board of Trade with respect to the Certifying and Examination of Meters.

"I. The Inspector should satisfy himself that a meter is of some construction and pattern and has been fixed and connected with the service lines in some manner approved by the Board of Trade. If the Inspector has reason to think that a meter does not comply with these conditions, he should take steps to ascertain whether the meter in question is in accord with the sealed specimen deposited with the Board of Trade.

"II. A meter should be considered by the Inspector to be a correct meter if, being a meter intended for more than 3 amperes, the error at one-tenth of its full load and above this point does not exceed + or − 2½ per cent. In the case of meters intended for currents not exceeding 3 amperes, the error must not exceed + or − 3½ per cent.

"The Inspector should generally satisfy himself as to the accuracy of the meter by testing at, say, 3 different loads, which may be taken at about ¼, ½, and ¾ of full load."

Copies of the specifications and drawings of any meter approved since June 1900 can be obtained by electric inspectors from the Board of Trade Electrical Standards Laboratory, 8 Richmond Terrace, Whitehall, London, S.W., on payment of the cost of reproduction.

It may be of interest to give here the limits of error prescribed, according to the German law of 1st June 1898, by the Physikalisch-Technische Reichsanstalt, Charlottenburg, Germany, with reference to meters. A difference is made between the errors of meters for approval and of meters for commercial use, and with reference to the latter these limits are defined as follows:—

Direct Current Meters.—Between full load and one-tenth full load the error must not exceed $\frac{6}{1000}$ of the maximum capacity of the meter, plus $\frac{6}{100}$ of the particular load at which the meter is used, and at $\frac{1}{25}$ full load the error must not exceed $\frac{1}{100}$ of full load. For meters which are used in lighting installations, these definitions only apply when the load is not less than 30 watts.

During times of no load it is prescribed that the meter shall not run backwards or forwards at a rate exceeding $\frac{1}{200}$ of the speed corresponding to full load.

Alternating and Polyphase Meters.—The definitions given above also apply in this case, with the restriction, however, that when a phase difference exists between the voltage and the current, the error, as defined above, must be expressed in hundredths of the load at which the meter is used, and to the number thus obtained in hundredths must be added double the tangent of the angle of phase displacement. By the angle of phase displacement is to be understood, that angle the cosine of which is equal to the power factor. All magnitudes used in estimating errors are to be taken with the same sign.

With reference to meters for *approval*, it is prescribed that the errors must be within half the limits as stated for meters for commercial use. With alternating current meters, however, the whole of the additional error (2 tan ϕ) is reckoned, ϕ being the phase difference between the pressure and the current. The above error limits, expressed in percentages of the load at which the meter is used, are, for direct current meters for commercial use, as follows:— + or − 6·6% at full load, + or − 6·8% at ¾ load, + or − 7·2% at ½ load, + or − 8·4% at ¼ load, + or − 12% at $\frac{1}{10}$ load.

For alternating current meters for commercial use these errors are all increased by 2 tan ϕ, *e.g.* at full load the error must not exceed + or − (6·6% + 2 tan ϕ). An approved meter, on the other hand, at full load must not have a greater variation from accuracy than + or − 3·3%, if for direct current, and + or − (3·3% + 2 tan ϕ), if for alternating current, and so on for the other loads.

In this country no difference in the error limits is made in the case of alternating current meters for loads which contain self-induction or capacity. The error limit for any particular inductive load is easily obtained. This is best illustrated by a couple of examples. When the maximum current is flowing in a circuit of power factor equal to one-half ($\cos \phi = \cdot 5$), the inductive load ($v.c. \cos \phi$) corresponds to one-half of the maximum load when the current and pressure are in phase. The error limit is in this case the same as that for one-half of full load when the power factor is unity. If, on the other hand, the current be under one-fifth of the maximum, the power factor being the same, then the inductive load corresponds to one less than one-tenth of full non-inductive load, and the error should not exceed, say, + or − 5%. It should be borne in mind that the percentage error of a meter is the percentage difference in the *load* as indicated by the meter and the true load, the *load* ($v.c. \cos \phi$) being quite generally the product of the volts, amperes, and power factor. When the power factor is unity, the load is simply the product of the current and the pressure. If, in addition, the pressure be constant (i.e. v is constant and $\cos \phi = 1$), then the terms 'load' and 'current' become synonymous, but in no other case.

Permanency of Calibration.—There are many agencies at work which tend to increase the inaccuracies of a meter in use, and in the case of motor meters they are—loss in magnetism of the permanent magnets, unless properly aged; bearing friction; friction of the integrating train, and of the gear connecting it with the meter axle; brush friction in commutator meters; fluid friction in mercury motor meters; temperature variations and, in the case of energy meters, the charring of the shunt coils, with a consequent increase in their electrical resistance, producing a diminished shunt field, and with it a smaller driving torque. The importance of the proper ageing and construction of the permanent magnets, and also their position in relation to the driving system of the meter, cannot be over-estimated. Mr G. Hookham, in his paper on "Permanent Magnet Circuits,"* showed the possibility of constructing magnets in which a considerable and permanent residual induction might be obtained, and pointed out the importance of the length of a magnet with reference to its cross section to obtain permanency.

The vital necessity that a so-called permanent magnet should retain its magnetic field unimpaired indefinitely will be readily grasped when it is remembered that the resisting torque exerted on the disc which rotates between the pole-pieces of the permanent magnet, forming the usual magnetic brake, varies as the square of the magnetic induction in the air-gap between the poles. The retarding torque† may be expressed mathematically as

$$T = K. B^2. r^2. \omega,$$

where B is the induction density, ω is the angular velocity of the brake disc, r is the radial distance from the axle of the brake disc to the poles, and K is a constant, depending on the shape of the polar area, the dimensions of the air-gap, and the conductivity of the brake disc. A slight loss in the strength of the magnetic field of the permanent magnet will, therefore, produce a very considerable diminution in the retarding torque, an increase in the speed of the armature, and the meter will read high. The retentivity of the permanent magnet should also not be affected by the passage of a short-

* *Philosophical Magazine*, Feb. 1888; also *Electrical Review*, vol. xxxvii. p. 476.

† "A Frictionless Motor Meter," by S. Evershed, *Jour. Proc. Inst. El. Eng.*, part 146, vol. xxi.

circuit current through the meter. The abnormal magnetic flux which emanates from the series coils during a short-circuit, and the subsequent rapid rate of change which takes place in the density of this field after the fuse has blown, is sufficient to render unaged magnets unfit for further use, and the accuracy of the meter is destroyed. Another feature which lends much to the immunity of the permanent magnets, from the weakening effects of the main current flux, is to place them so that their greatest length or path of permanent flux is at right angles to the magnetic axis of the series coils. This result was experimentally discovered by Mr T. Duncan, of America,* some years ago. In many cases permanent magnets are further protected from the effects of the series coils by means of iron shields separating them from the electrical element of the meter.

The general method of adjusting the speed of the motor meter having a magnetic brake is to alter the position of the brake magnet relatively to the brake disc, the brake magnet being suitably mounted for this purpose. The adjustment is made by moving the magnet either nearer to or further away from the axis of the disc. It was shown above that the brake torque is proportional to the square of the radial distance from the axis to the poles of the magnet, and consequently it is most essential, after an adjustment has been made, that the magnet be very firmly secured, so that its position remain unaltered during transit, and be not affected by temperature variations. The best method of adjustment is not to alter the position of the magnet at all, but to shunt some of the field of the air-gap of the magnet through an alternative path, and by increasing or decreasing the magnetic reluctance of this alternative magnetic circuit, the brake field will be increased and the speed of the meter decreased, or the brake field will be weakened, and the speed correspondingly increased. This or an analogous method is used in some meters, and the small iron screws, by means of which the brake field is altered, can be securely locked, so that their position is invariable after the adjustment is complete.

The greatest wear in a motor meter, without a commutator, is in connection with the jewel bearing which supports the revolving element. Friction at the bearings does not remain constant, but tends to increase with the prolonged use of the meter. It is largely affected by the character of the installation in which the meter is fixed, *i.e.* the presence or absence of vibration, dirt, moisture, and insects. Too much attention cannot be bestowed upon the proper apportionment of the weight of the revolving element and the supporting jewel bearing, which should in every case be flexibly supported.

In the case of commutator motor meters, the main source of trouble is the friction which occurs at the brushes on the commutator. Various devices are used to eliminate this error, a few of which will be found in the descriptive chapters dealing with this type of meter. The commutator should not be liable to tarnish, and its surface must always be kept clean and bright. This part of the meter should therefore be readily accessible to supervision without having to remove the main meter cover. Mainly with the view to eliminating brush friction, mercury motor meters are used, in which case the mercury serves to conduct the current to and from the revolving armature, which in this case usually consists of a copper disc, immersed in the mercury bath. In the old type of Ferranti meter the mercury constitutes the armature itself; the company, however, use a copper disc in their new type.

* American Patent, No. 550823, 1895.

The friction of the mercury has to be compensated for at high loads, as otherwise its increase in friction in this region introduces errors. In the Ferranti meter, in which the mercury acts as the armature, the friction of the mercury is used to produce the retarding couple on a light fan which is immersed in the mercury bath. With this meter, which is of the ampere-hour type, the driving torque is proportional to the square of the current, and the resisting torque of fluid friction is proportional to the square of the speed, so that, neglecting other disturbing influences, when balance occurs the speed is proportional to the current. The remaining source of friction in motor meters is in the gear connecting the meter axle with the integrating train, and in the train itself. The wheels, pinions, and gears should all be very carefully constructed and aligned, so that the error they introduce is reduced to a minimum and is not of a variable nature. Further, it is important that the worm on the meter axle should be made of suitable alloy, so that in damp situations it does not rust, and so impair the correct working of the meter.

Besides the brake magnets, there are other parts of the meter which have to be adjusted, and the adjustments consist in the alteration of the position of a sliding connector, a small piece of iron, or some other support. It is of the highest importance that all such regulating devices should be so secured that, after having been finally set, their position should be invariable and unaffected by any disturbing influences during transit, installation, or use. In fact all adjustments should be permanently sealed as well as the main meter cover.

Guarantee.—A meter is usually guaranteed by the manufacturer for an average period of one year. The author, however, would recommend meter makers to extend this period and give a three years' guarantee, provided that they be allowed to permanently seal their meters, and that the guarantee should terminate on the seals being broken. In such a case, if a meter should be found to register incorrectly after it has been properly tested at the station, or after its installation in a consumer's premises, it would be at once returned to the manufacturer, who would either replace it or repair it, defraying all costs. He would in this manner be able to ascertain exactly the cause of the improper working of the meter, find out the weak features of the particular type, and effectually remove them. It is, however, quite impossible for him to arrive at the root of any trouble, if the meter cover have been previously removed and the adjustments in any way interfered with. If faults should develop in a meter after the expiration of the guarantee period, meter manufacturers would doubtless be prepared, at a reasonable charge, to repair the meter or exchange it, and renew the guarantee. This should result in not only effecting improvements in meters, but also in materially reducing the charges for maintenance and repairs of the meter department of a station. It certainly seems inadvisable for a central station to undertake the manufacture or semi-manufacture of meters, with its attendant expense and restrictions. The station should, however, be provided with a highly efficient testing equipment, and the whole attention of the meter staff should be directed to the systematic testing of meters and all measuring instruments in the station, the periodic testing and supervision of meters *in situ*, and the checking of meter readings and meter accounts.

Series and Shunt Losses.—The current flowing in the series circuit of a meter produces a drop in voltage, which causes a diminution of the pressure across the circuit beyond the point of connection of the meter, and power is also wasted. The series loss is generally small, and should not exceed 6 watts,

with a greater drop than 1 volt at full load in a 5-ampere meter, and be negligibly small in the larger sizes. This waste of power and drop in voltage only occur when current flows in the particular installation, and both reach a maximum when the current taken is a maximum. The drop is the most important loss in the series circuit, as it reduces the voltage across the consumer's lamps.

The series loss is borne by the consumer, and not by the station. If V be the supply voltage across the consumer's circuit in front of the meter, and A be the full load current, supposed constant during n hours, then, assuming no errors in the meter, the reading will give $\frac{V.A.n}{1000}$ units as the energy consumed under these conditions. If v be the drop in the meter, then the consumer actually uses $\frac{(V-v).A.n}{1000}$ units, as the pressure across his circuit beyond the meter is $(V-v)$ volts. He therefore pays for $\frac{V.A.n}{1000}$ units, but only consumes $\frac{(V-v).A.n}{1000}$ units. Moreover, owing to the drop in pressure, the candle-power of his lamps is largely reduced. He therefore suffers loss in two directions.

In an energy meter power is wasted both in the main current and in the pressure current circuits. The most important loss is that occurring in the pressure circuit, and is entirely borne by the station. It represents a very considerable annual loss in revenue, as this waste is continuous whether current be taken or not. Assuming as low a shunt loss as 1 watt per 200 volts, the annual loss to the station per meter is 8·76 B.O.T. units; and, on the other hand, with a loss in the shunt of 10 watts per 200 volts, the annual loss per meter would be 87·6 B.O.T. units. It is highly important, therefore, that these shunt losses should be small, especially in connection with the supply of current to very small consumers, who at the most have only two or three 16 c.p. lamps burning at a time.

It may be as well to point out here that the connections between the pressure and the current circuits in an energy meter should be made on the supply side of the current terminals, so that it is impossible for the shunt loss to be registered by the meter. The connections should also be easily accessible, to permit separation of the pressure and current circuits for testing.

Criterions of a Meter.—The driving torque, weight of the revolving element, friction, and the shunt losses at a definite voltage (the latter in the case of an energy meter) are all so intimately connected and dependent on one another, that the figures relating to these quantities should, wherever possible, be always given together. In general the weight of the revolving element gives a very approximate idea of the bearing friction, which is proportional to the weight on the pivot.

A high driving torque is very desirable, but does not, *per se*, give any indication as to the probable behaviour or possible permanence of performance of a meter. To gain an idea of how a meter will probably function in service, it is necessary to know the values of the torque, weight, and frictional retarding torque.

A high driving torque can be obtained by increasing the weight of the moving element. This method is not very satisfactory in operation, as the meter is less responsive to small differences in the current flowing in the circuit

than one which has an equal ratio of torque to weight, but a lighter revolving element; bearing friction and the wear on the jewel are also increased.

On the other hand, the weight of the revolving element must not be made too light, as a sudden heavy increase in the current may twist it, and cause excessive hammering on the jewel. The real determining factor in the satisfactory operation of a meter is a high ratio of driving torque to weight.

The ratio of the driving to the frictional retarding torque and that of the driving torque to the weight should be as large as possible, as then variations and increases in friction, which cannot be completely excluded when a meter is in use, become of relatively small value in affecting the working of the meter. On account of the stability and rigidity of the moving element and the cost of the meter, these factors cannot, however, be carried beyond certain limits. A high ratio between the driving torque and weight can, moreover, be obtained when both the figures relating to each of these quantities are small, so that two meters having totally different driving torques and weights may give the same ratio; and without the actual figures of the torques, weights, etc., it is not possible to say which is the better meter of the two.

In the accompanying three tables (I.–III.) some average figures are given of the driving torque in millimetre-grammes; the weight of the revolving element in grammes; the ratio of the driving torque to weight, *i.e.* the driving torque per unit weight of revolving element; the full load speed in revolutions per minute; the shunt loss in watts and the annual shunt loss in Board of Trade units of a few meters in commercial use. In connection with the mercury motor meters, the ratio of the driving torque to the weight of the revolving element is not comparable with this ratio of the other types, as in mercury motor meters the weight of the revolving part does not represent the pressure on the jewel bearing. The series loss, although important, is not given in the tables, as it varies with the load, reaching a maximum at full load. The annual loss in the series circuit of a meter could therefore only be given by assuming an average load throughout the year, so that the total annual loss due to both the series and shunt circuits would only be approximate, and not of very much value. The annual loss of energy in the shunt of a meter can, however, be definitely stated, as the power wasted in the shunt is practically invariable; moreover, the B.O.T. units wasted in the pressure circuit represent the actual loss to the supply station.

Selection of a Meter.—The selection of a meter depends on a variety of factors, such as local conditions, the nature of the supply current, whether continuous or alternating, the voltage, the function of the meter, the class of consumer, price, guarantee, shunt losses, and probable cost of maintenance and repairs. In the case of a continuous current supply at approximately constant pressure, from considerations of initial capital outlay, the annual loss in the pressure circuit of an energy meter, maintenance, depreciation and interest charges, the ampere-hour meter is decidedly to be preferred to the watt-hour type, especially in the case of small consumers, whose actual bill may not be a very large one, but who are amongst the most profitable class of consumers to a supply station. The ampere-hour meter does not actually measure what the consumer pays for, namely, electrical energy, but is calibrated to register the units consumed at the declared voltage of supply, on the assumption that this voltage is kept constant. It is unaffected by voltage variations, so that, if the pressure across the circuit to which it is connected be above the declared value, a loss of units is incurred due to its use. It is, however, incorrect to draw from this the inference that a station using ampere-hour meters will

TABLE I.—CONTINUOUS CURRENT QUANTITY MOTOR METERS.

Size :—5 Amperes. 200 Volts.

Type.	Name of Company.	Driving Torque in Mm.-gms.	Weight of Moving Element in Gms.	Ratio of Driving Torque to Weight.	Full Load Speed. R.P.M.	Remarks.
C.R. . .	G. Braulik (Luxsche Industriewerke)	50	25	2·000	100	Commutator motor meter, shunted type, with magnetic brake. Flat coils on brake disc.
O'K. . .	British Thomson-Houston Co.	440	190	2·316	250	Commutator motor meter, shunted type, no brake at all. Runs up to speed until back E.M.F. counterbalances drop across meter terminals.
R.A. . .	The Electrical Co. (Tn Allgemeine Elektricitäts Gesellschaft)	137	100	1·370	200	Commutator motor meter, shunted type, with magnetic brake.
1897 . .	Chamberlain & Hookham	50	26*	1·923	150	Mercury motor meter. Disc armature and magnetic brake. 25 amperes. * Weight in air.
1901 . .	Chamberlain & Hookham	10	22*	0·454	90	Mercury motor meter. Cylinder armature and magnetic brake. * Weight in air.
	Ferranti, Ltd.	20	1·6*	12·375	110	Mercury motor meter. Fluid brake. 10 amperes. * Weight of spindle and fan in air.

TABLE II.—CONTINUOUS CURRENT ENERGY METERS WITHOUT IRON.

Size:—5 Amperes. 200 Volts.

Type.	Name of Company.	Driving Torque in Mm.-gms.	Weight of Moving Element in Gms.	Ratio of Torque to Weight.	Full Load Speed. R.P.M.	Shunt Loss W. Watts at 200 Volts.	Annual Loss in Shunt, B.O.T. Units =W. × 8·76.	Remarks.
Eclipse N.R.	G. Braulik	150	86	1·744	50	4	35·04	Energy motor meter, with commutator and magnetic brake.
Eclipse B.N.R.	G. Braulik	100	84	1·190	50	4	35·04	Do.
A.	British Thomson-Houston Co.	300	250	1·2	45	6	52·56	Do.
Duncan	Duncan Electric Mfg. Co. (U.S.A.)	155	141·75	1·093	36·66	6·55	57·38	Do.
A.G.	The International Electric Co. (Mix & Genest)	78	70	1·114	150	4	35·04	Do.
G.W.	Siemens-Schuckert (Siemens Bros.)	220	230	·957	60	5	43·8	Do.
K.G.	The Electrical Co.	12·5	59	·212	48	3	26·28	Oscillating watt-hour meter, with magnetic brake.
1902	Chamberlain & Hookham	26	91	·274	50	13	113·88	Watt-hour mercury motor meter, with iron and permanent magnetic brake. Switch-board type.
Brush-Sangamo	The Sangamo Electric Co., U.S.A. (The Brush El. Eng. Co.)	24	60	·40	33⅓	8–9	70·08–78·84	Watt-hour mercury motor meter, with iron. No permanent magnets. Shunt field utilised to produce brake torque.

TABLE III.—SINGLE-PHASE INDUCTION METERS FOR INDUCTIVE LOADS.

Size :—5 Amperes. 200 Volts. 50 Cycles per Sec.

Type.	Name of Company.	Driving Torque in Mm.-gms.	Weight of Revolving Element in Gms.	Ratio of Driving Torque to Weight.	Full Load Speed. R.P.M.	Shunt Loss W. Watts at 200 Volts and 50 ~ per Sec.	Annual Loss in Shunt, B.O.T. Units = W. × 8·76.	Remarks.
Aron . .	Aron Electricity Meter, Ltd.	10	24	·417	100–120	1·5	13·14	
"Batault" E.	Bat Meter Co.	35	50	·70	60	1	8·76	
A.C.T. . .	British Thomson-Houston Co.	33·3	60	·556	55	0·5	4·38	
Sub-A. . .	British Westinghouse Co.	13	15	·867	50	2·5	21·9	
F.E.M. . .	G. Braulik	19	15	1·267	50	3·5	30·66	
	Chamberlain & Hookham	2·4	31	·0774	80	3	26·28	For non-inductive loads only.
K.J. . .	The Electrical Co.	68·9	32	2·153	60	3	26·28	
Ferranti-Hamilton	Ferranti, Ltd.	11	18·5	·595	40	2·9	25·4	
K. . .	Fort Wayne Electric Co., U.S.A.	35	44·5	·787	30	2	17·52	
A.W. . .	International Electric Co.	100	35	2·857	80	2	17·52	
Brush-Gutmann	The Sangamo Electric Co.	16	28	·571	50	2½	21·9	
W_2. . .	Siemens-Schuckert	70–80	30	2·667	40–60	2·5	21·9	
Model G., Type S.	Stanley Instrument Co., U.S.A.	40	25	1·6	30	1·5	13·18	Magnetic suspension meter.
Model H., Type H.	Ditto.	25	25	1·0	20	1·08 *	9·46 *	Jewel bearing meter. * Loss in shunt at 200 volts, 60 ~ p. sec.

necessarily suffer a loss of revenue, because the voltage is, in general, some 2 per cent. above its normal value at the feeding points in the distributing system. Some circuits will have their voltage above the normal, and with ampere-hour meters there will be a loss; others will be at the correct voltage, and there will be neither loss nor gain; on the other hand, there will be, again, other circuits across which the voltage will be below its right value, so that in this case there will be a distinct gain. On the whole, in a well-designed system of distribution a very fair balance will be obtained, and the disadvantage of the ampere-hour meter in this respect is more apparent than real; in fact, it may be a source of gain. The loss or gain, according as the voltage is high or low, is readily estimated. If the ampere-hour meter register U units in the year, on the assumption that the voltage V is constant, whereas it is always 2 per cent. above this value, then the loss to the station is $\cdot 02V \times U \times d$, where d is the selling price per unit. If the voltage be low instead of high, and by the same amount, this result will represent the gain to the station.

The question to be decided with ampere-hour meters is whether they shall be of the electrolytic or motor type. Electrolytic meters have the advantage of being cheaper than motor meters, but they certainly require more attention, as they have to be either re-set or re-filled after definite periods; they are more or less unmechanical, and do not comply with the general conditions of practice so satisfactorily as a well-designed motor meter.

Clock meters register correctly, however small the current may be; they have a wide range and a high degree of accuracy, but are expensive and somewhat complicated. For special purposes they are particularly well adapted, and the three-wire type correctly measures the energy taken in a three-wire direct current or single-phase alternating current network, whatever the distribution and nature of the loads on the two sides of the system. This is not the case with the ordinary three-wire energy motor meter, which correctly registers the energy in such a system under certain conditions only.

When the supply is an alternating current, the meter used invariably measures electrical energy, and the relative shunt losses play a very important part in the selection of the meter, besides its actual cost. The performance of the meter on inductive loads is one which also must not be lost sight of, especially if in the circuits a phase displacement between the current and the pressure be likely to occur. In fact, all meters intended for alternating current supply circuits should be suitable for inductive loads, whether the loads be so or not. As already mentioned, the meters for such circuits are on the induction principle, and only these should be used, on account of their simplicity, ease of adjustment, low cost and low shunt losses relatively to commutator motor meters without iron, their considerably smaller frictional resistances to motion, the total elimination of brush friction and commutators, or rubbing contacts of any description, and the absence of any current from the supply circuit in the revolving armature, which is simply a disc or cylinder of aluminium or copper.

Capacity of a Meter.—The capacity of a meter is generally dependent on the maximum capacity of the installation in which it is placed. It seems, however, advisable to use meters having a smaller capacity than the maximum of the circuits it controls, and to have a relatively large overload capacity, the degree of which varies with the nature of the load of the particular circuit to which the meter is connected. As a general rule, a house-service meter works mostly in the region of 20 to 30 per cent. of full load, and is, therefore, not working at the best part of its curve, as, usually, the least error

occurs between half and full load. The full load of an electric lighting installation in a private house is only taken on special occasions, which are not of frequent occurrence, so that, if the capacity of the meter be, in such a case, made to correspond to half the maximum number of lamps installed, and be capable of carrying a large overload current for short periods, it would be much more efficient, would probably cost less, and would be mainly operating near its full load capacity. The meter should, consequently, be less dependent on the variable nature of friction at low loads, and start better when only one or two lamps are switched into circuit.

A meter should, with reference to its starting current, register with certainty the minimum load of the circuit to which it is connected.

Meters approved by the Board of Trade.—Of the large number of different types of meters in commercial use, only a very few have received Board of Trade approval. All such approvals are published in the *Official Gazette* immediately after intimation to the manufacturers, and below are given, in chronological order, in the three tables IV.–VI., the approvals which have been given up to the time of going to press.

TABLE IV.—CONTINUOUS CURRENT METERS APPROVED BY THE BOARD OF TRADE.

Day.	Month.	Year	Name.	Company.	Remarks.
9	Oct.	1896	Hookham	Chamberlain & Hookham	Ampere-hour mercury motor meter. Disc armature.
9	Oct.	1896	Ferranti	Ferranti, Ltd	Ampere-hour mercury motor meter. Mercury constitutes armature. Brake consists of fan in mercury.
26	July	1898	Aron	Aron Electricity Meter, Ltd.	Watt-hour clock meter.
25	July	1900	Bastian	The Bastian Meter Co.	Water electrolytic meter.
24	Sept.	1901	Schattner	Engineering Instruments, Ltd.	Prepayment continuous current ampere-hour meter. Abandoned.
19	Feb.	1902	O'K.	The British Thomson-Houston Co.	Ampere-hour motor meter.
22	May	1902	Hookham	Chamberlain & Hookham	Ampere-hour mercury motor meter. Cylindrical armature.
15	May	1903	Elihu Thomson	The British Thomson-Houston Co.	Watt-hour motor meter. Type A.
28	May	1903	Wright	The Reason Manufacturing Co.	Mercury electrolytic meter.
14	Feb.	1905	Bastian "N" Type	The Bastian Meter Co.	Water electrolytic meter.

TABLE V.—ALTERNATING CURRENT METERS APPROVED BY THE BOARD OF TRADE.

Day.	Month.	Year.	Name.	Company.	Remarks.
8	Oct.	1891	Shallenberger	The British Westinghouse Co.	Ampere-hour induction meter. Abandoned in this country.
23	March	1899	Aron	The Aron Electricity Meter, Ltd.	Clock meter.
12	July	1899	Aron	Do.	For two-phase or three-phase circuits. Clock meter.
17	May	1901	Shallenberger	The British Westinghouse Co.	Abandoned in this country.
24	Sept.	1902	Westinghouse	Do.	Watt-hour induction meter.
8	March	1904	Stanley	Do.	Watt-hour induction meter. Replaced in this country by Westinghouse meter.
12	May	1904	Ferranti-Hamilton	Ferranti, Ltd.	Watt-hour induction meter.
27	Feb.	1905	K.J.	The Electrical Co., Ltd.	Watt-hour induction meter.

TABLE VI.—MAXIMUM DEMAND INDICATORS APPROVED BY THE BOARD OF TRADE.

Day.	Month.	Year.	Name.	Company.	Remarks.
9	July	1903	Atkinson-Schattner	Engineering Instruments, Ltd.	Based on the electro-magnetic principle.
8	June	1904	Wright	The Reason Manufacturing Co.	Based on the thermal principle.

CHAPTER II.

GENERAL PRINCIPLES OF CONTINUOUS CURRENT METERS.

General Equations—Law of the Chemical Meter—Electro-magnetic Action—Laws of the Motor Meter with Brake—Law of the Motor Meter without Brake—Law of the Clock Meter—Thermal Effect—Behaviour of Continuous Current Three-wire Energy Motor Meters.

General Equations.—The electrical energy delivered to a circuit during any given interval of time is expressed by the general equation

$$E = \int_{T_1}^{T_2} c.v.dt, \quad . \quad . \quad . \quad . \quad . \quad (1),$$

where c and v are respectively the instantaneous values of the current flowing in the circuit and the potential difference applied to its terminals, T_1 and T_2 denoting the commencement and termination of the period under consideration, and dt is the short interval during which the power, $c.v$ is supposed to remain constant. If c be the value of the current in amperes, v be the pressure expressed in volts, and the hour be taken as the unit of time, then the electrical energy is expressed in watt-hours.

The function of an electricity meter is to register the electrical energy consumed in a given period, and a meter that performs the operation expressed on the right-hand side of equation (1) is called an energy meter, or more usually a watt-hour meter. In some instances these instruments are still erroneously termed recording wattmeters. A recording wattmeter does not measure energy, *i.e.* does not integrate the values of $c.v.dt$, but measures power, and traces out on record paper, mounted on a continuously revolving drum, a curve, the ordinates of which represent the values of the power supplied to the circuit.

In electricity supply systems in which the supply pressure is kept practically constant, v is a constant, and the general equation may be written

$$E = v\int_{T_1}^{T_2} c.dt, \quad . \quad . \quad . \quad . \quad . \quad (2).$$

An electricity meter in this case does not integrate the different values of the energy, but simply the quantities of electricity in ampere-hours; in other words, it performs the operation $\int_{T_1}^{T_2} c.dt$, and is then called a quantity or an ampere-hour meter. A quantity meter is sometimes designated a coulomb

meter. The term 'coulomb meter' should, however, not be used in this sense, as the coulomb represents one ampere-second, whereas in quantity meters the unit of quantity is the ampere-hour.

Quantity meters are usually calibrated so that their indications are in watt-hours, hectowatt-hours, or kilowatt-hours at the voltage of the circuit to which they are connected.

If both c and v be constant, that is, the power taken be always the same, then

$$E = v.c.\int_{T_1}^{T_2} dt,$$

or

$$E = W\int_{T_1}^{T_2} dt, \quad . \quad . \quad . \quad . \quad . \quad . \quad (3),$$

W being the power in watts. For this purpose hour-meters are used, which consist of clocks electrically controlled, whose function is to register the time in hours during which current has been flowing in the circuit.

If the current c remain constant, then equation (1) becomes

$$E = c\int_{T_1}^{T_2} v.dt, \quad . \quad . \quad . \quad . \quad . \quad (4).$$

A meter which measures the quantity expressed under the integral is termed a volt-hour meter.

The above equations hold for both continuous and alternating current, provided that c and v represent the instantaneous values of the current and pressure. In a continuous current system the instantaneous values are identical with the effective values, as measured by an ammeter and voltmeter. This is, however, not the case with alternating currents, as both the current and the voltage are periodic functions, and in general sine functions of the time, varying in a cyclic manner both in sense and magnitude, and are also not necessarily in phase with one another. If in an alternating current system c' and v' denote the effective or virtual values (the virtual value is the square root of the mean of the squares of the values during half a period) of the current and pressure as given by an alternating current ammeter and voltmeter, and ϕ be the phase displacement between c' and v', then the power is $c'.v'.\cos\phi$, $\cos\phi$ being the power factor of the circuit. Equation (1) then becomes

$$E = \int_{T_1}^{T_2} c'.v'.\cos\phi dt, \quad . \quad . \quad . \quad . \quad . \quad (5),$$

and the other equations are modified in a similar manner.

Law of the Chemical Meter.—Either the chemical, electro-magnetic, or thermal action of a current is utilised in the construction of meters. An electrolytic meter depends on the chemical action of a current of electricity, and is essentially a quantity meter. It follows, from the nature of electrolytic action, that such a meter can only be used for direct currents. When a current of electricity passes through certain liquids, such as dilute acids and solutions of metallic salts, chemical decomposition takes place.

The current enters the electrolytic cell by the one conductor, the anode,

and leaves it by the other conductor, the cathode, the electro-positive elements of the electrolyte being deposited at the cathode and the electro-negative elements at the anode. The amount of electrolytic decomposition, *i.e.* the amount of metal deposited or of gas evolved, depends on three factors, *i.e.* the strength of the current, the time-interval during which the current flow lasts, and the nature of the electrolyte, or the electro-chemical equivalent of the substance liberated.

Expressed mathematically,

$$M = z\int_{T_1}^{T_2} c.dt, \qquad \ldots \qquad (6),$$

where M denotes in grammes the amount of metal or gas set free in $T_2 - T_1$ hours, Z is the electro-chemical equivalent expressed in grammes per ampere-hour, and c is the current in amperes, supposed constant during the small interval of time dt.

From (6)

$$\int_{T_1}^{T_2} c.dt = \frac{M}{z},$$

or, the ampere-hours are proportional to the amount in grammes of the electrolytic deposit. The electro-chemical equivalent in grammes per ampere-hour of water is ·3356, of mercury from a mercurous salt 7·466, of zinc 1·213, and of copper from a cupric solution 1·178. Thus 3·36 grammes of water are decomposed per Board of Trade unit at 100 volts, and in a water-decomposing meter the whole current to be measured flows in general through the electrolytic cell.

In the case of chemical meters in which the electrolyte consists of a solution of a metallic salt, only a small fraction of the total current is used to effect the decomposition, as the amount of deposit would otherwise be excessively large, amounting per Board of Trade unit at 100 volts to 74·7 grammes for mercury and 12·13 grammes for zinc. In a mercury electrolytic meter, the fluidity of the metal is made use of for its measurement by volume instead of by weight.

Electro-magnetic Action.—The electro-magnetic effect of a current flowing in a conductor is the external action which it produces, and is due to the creation of a magnetic field in the medium surrounding the conductor. A circuit conveying a current is acted upon by a magnet, or by an adjacent circuit traversed either by the same or a different current. This electro-dynamic action between currents, or between a current and a magnet, is utilised in meters to produce a rotational or oscillatory motion, and to influence an already moving system, such as a pendulum. In motor meters the motion is one of rotation, and results from the interaction of two magnetic fields, generated either by two current systems, the one stationary and the other movable, or by one movable current system and a fixed permanent magnet. In oscillatory and pendulum meters the same electro-dynamic principle is involved, but in the former the moving system oscillates, and in the latter the periodic time of the pendulum is either increased or decreased. Such meters are at the present day used almost exclusively for direct currents, although, provided that they contain no iron, they are applicable to alternating current measurements. Alternating current meters are, however, based on the principle of induction, which is explained in Chapter VII.

Laws of the Motor Meter with Brake.—In watt-hour motor meters, the speed of rotation of which should be proportional to the power, the one magnetic field is due to the main current flowing in the circuit, and the other magnetic field is created by a current proportional to the supply pressure. The main current, which is the variable current to be measured, flows in one or two stationary coils, and the pressure current, which is approximately constant, traverses the revolving armature, having a commutator and brushes, the motor constituting an electro-dynamometer with a continuously revolving coil.

In ampere-hour motor meters, the speed of rotation of which should be a measure of the current, the one field is variable, and is produced by the whole or a fractional part of the main current in the armature, and the other field is either fixed, and due to a permanent magnet, or it is variable with the current, and is created by a series electro-magnet.

The turning moment, or driving torque, exerted on the armature is proportional to the product of the two magnetic fields. These two magnetic fields in a watt-hour motor meter are made dependent, the one on the main current, and the other on the pressure current, the latter being proportional to the supply voltage. In an ampere-hour motor meter, however, either the two magnetic fields are produced by the main current, or this current only gives rise to one magnetic field, and the other is then a fixed field, due to a permanent magnet.

If C denote the main current in amperes and V the applied P.D. in volts, then for a watt-hour motor meter

$$D = K_1.C.V, \quad . \quad . \quad . \quad . \quad . \quad . \quad (7),$$

for an ampere-hour motor meter with a permanent magnet

$$D = K_2.C, \quad . \quad . \quad . \quad . \quad . \quad . \quad (8),$$

and for an ampere-hour motor meter with a series electro-magnet

$$D = K_3.C^2, \quad . \quad . \quad . \quad . \quad . \quad . \quad (9).$$

The speed of rotation must always be proportional to the power or the current, and each value of the electrical magnitude must correspond to a perfectly definite speed, which must not vary, provided the particular electrical quantity remains the same. This condition of no acceleration is satisfied when the armature is at rest, and for it to be fulfilled when motion ensues, or, in other words, to obtain steady motion, an opposing torque must be provided which will equilibrate the torque exerted by the electrical system producing motion. If T denote the resisting torque, then the condition for steady motion is

$$D - T = 0.$$

The retarding torque of the brake system employed in the meter must be an exactly similar function of the speed, as the driving torque is of the electrical magnitude.

When steady motion has been established, if n denote the revolutions per minute of the armature when

$$D = K_1.C.V, \quad \text{then}$$
$$T = K'_1.n.$$

$$\therefore \qquad n = \frac{K_1}{K'_1}.C.V.$$

When $D = K_2 . C$, then
$T = K'_2 . n$.

$$\therefore \quad n = \frac{K_2}{K'_2} . C.$$

And finally when $D = K_3 . C^2$, then
$T = K'_3 . n^2$.

$$\therefore \quad n = \sqrt{\frac{K_3}{K'_3}} . C.$$

Hence it follows that in energy meters the speed of rotation must always be proportional to the *power*, and in quantity meters to the *current*, so that the number of revolutions executed in a given time will be proportional to the energy or quantity of electricity delivered in that time.

The retarding torque proportional to the speed is produced by the well-known magnetic brake, which consists usually of a light copper or aluminium disc, which rotates between the poles of a permanent magnet. Foucault or eddy currents are induced in the disc as it rotates in the magnetic field, and the interaction between these eddies and the magnet exerts the resisting torque, which varies directly as the speed of rotation multiplied by the square of the intensity of the field. When the driving torque varies as the square of the current, a retarding torque proportional to the square of the speed has to be employed, and for this purpose air or fluid friction is used, but the result obtained is, in general, not very satisfactory, as this law for fluid friction holds within certain limits only, and the driving torque falls off much more rapidly than the current.

In a watt-hour motor meter the driving torque $D = K_1 . C . V$, and the brake torque $T = K'_1 . n$, and when the condition of steady motion has been established

$$K_1 . C . V = K'_1 . n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (10),$$

$$i.e. \qquad \int_{T_1}^{T_2} n \, dt = \frac{K_1}{K'_1} \cdot \int_{T_1}^{T_2} C . V . dt.$$

In the above no account has been taken of the various frictional resistances to motion—brush friction, bearing friction, friction between the counting train and gear, and air friction—and the result obtained is not quite correct. Denoting these retarding torques by F, then equation (10) becomes

$$K_1 . C . V = K'_1 . n + F,$$

$$i.e. \qquad n = \frac{K_1}{K'_1} . C . V - \frac{F}{K'_1}.$$

This last equation shows that the speed of the meter is not strictly proportional to the power.

In a well-designed meter the frictional term $\frac{F}{K'_1}$ is very small, and at high loads is inappreciable, but at low loads may seriously affect the registration of the meter. Friction is also a maximum when the meter passes from the state of rest to motion, and is also variable at slow speeds when the driving torque is small. To neutralise the effect of friction a constant supplemental

torque is added to the variable driving torque of the meter, and the complete law of the energy motor meter is then expressed by the equation

$$K_1.C.V + D_0 = K'_1.n + F \quad . \quad . \quad . \quad . \quad (11),$$

where D_0 is the additional driving torque, which should balance the frictional retarding torque F. The above consideration holds good when the motion is one of oscillation instead of rotation.

Law of the Motor Meter without Brake.—If the armature of a motor having S surface conductors (S denotes the number of conductors round the armature circumference) rotate at a speed of n revolutions per second in a field of total magnetic flux N, then the counter electro-motive force generated in it is

$$E = n.N.S.10^{-8} \text{ volts.}$$

If C_a be the current in the armature in amperes, r be its resistance in ohms, and V the P.D. across the brushes in volts, then

$$V = E + C_a.r.$$

The work done per second on the armature is $E.C.10^7$ ergs, and if D denote the torque in dyne-centimetres, the work per second is also given by $2.\pi.n.D$ ergs, so that

$$2\pi n D = E.C_a.10^7.$$

$$\therefore \qquad D = C_a . \frac{N.S}{2\pi} . 10^{-1}.$$

$$\text{Also} \qquad C_a = \frac{V - E}{r}.$$

$$\therefore \qquad D = \frac{10^{-1}}{2\pi} . \frac{NS}{r} . (V - E).$$

When the torque exerted is zero, *i.e.* D equals 0, then V equals E, or

$$V = n.N.S.10^{-8}.$$

From which it follows, if N be due to a permanent magnet, that the speed is proportional to the P.D. across the armature terminals, provided that the motor does no work and has no internal losses. If V be proportional to the current to be metered, the speed of the motor will vary directly as the number of amperes in the circuit.

A motor ampere-hour meter can be made on this principle when the motor is not allowed to do external work—for instance, in the generation of Foucault currents in a magnetic brake—and the armature current is approximately zero. On the passage of a current the motor armature is accelerated until its back E.M.F. balances the P.D. across the brushes, produced by the drop in volts in the low-resistance shunt, with which it forms a parallel circuit, and which carries the whole current of the installation.

Law of the Clock Meter.—If T denote the periodic time in seconds of a freely swinging pendulum, of mass M grammes and moment of inertia I, expressed in C.G.S. units, and if h denote in centimetres the distance between its centre of gravity and centre of suspension, g being the acceleration due to gravity in cms. per sec. per sec., then

$$T = 2\pi\sqrt{\frac{I}{Mgh}},$$

and the number of complete swings the pendulum executes in t seconds is given by

$$n=\frac{t}{2\pi}\cdot\sqrt{\frac{Mgh}{I}}.$$

When the bob of the pendulum is replaced by a coil energised by a current proportional to the voltage, and it be caused to oscillate over a coil traversed by the main current, due to the mutual attractions or repulsions between the coils, the pendulum will be either accelerated or retarded. The new periodic time, in the case of an accelerated pendulum, is given by

$$T_1=2\pi\sqrt{\frac{I}{Mgh+K.C.V}},$$

where K is a constant, and the number of oscillations in the time t will be

$$n_1=\frac{t}{2\pi}\sqrt{\frac{Mgh+K.C.V}{I}}.$$

This may be written

$$n_1=\frac{t}{2\pi}\sqrt{\frac{Mgh}{I}}\cdot\sqrt{1+\frac{K}{Mgh}\cdot C.V}$$

or $$n_1=n(1+K'.C.V)^{\frac{1}{2}},$$

where $$K'=\frac{K}{Mgh}.$$

The expression on the right-hand side of this equation can be expanded in a series by the Binomial Theorem, and

$$n_1=n.\left\{1+\frac{K'}{2}.C.V-\frac{K'^2}{8}.C^2.V^2+\frac{K'^3}{16}C^3.V^3-\ldots\right\}.$$

If the force due to the electrical system be small compared with that exerted by gravity, *i.e.* the term $\frac{K'}{2}CV<1$, the terms of the second degree and above can be neglected, and the series approximates to

$$\left(1+\frac{K'}{2}.C.V\right).$$

Then $$n_1=n\left(1+\frac{K'}{2}.C.V\right).$$

Therefore, in the short interval dt,

$$\frac{d(n_1-n)}{dt}=\frac{K'}{2}C.V\frac{dn}{dt}.$$

And $$\frac{dn}{dt}=\frac{1}{T}.$$

$$\therefore\quad CV=\frac{2T}{K'}\frac{d(n_1-n)}{dt}.$$

The electrical power is proportional to the difference in the rates of going of

two clocks having similar pendulums, the one swinging freely under the action of gravity, and the other being subject to electrical attraction or repulsion.

And
$$\int_{T_1}^{T_2} C.V.dt = \frac{2T}{K'} \cdot \int_{T_1}^{T_2} d(n_1 - n) \quad . \quad . \quad . \quad . \quad (12),$$

or the electrical energy consumed in a given period is proportional to the total difference in the number of swings made in that time by the two pendulums. A similar result is obtained by replacing the bob by a permanent magnet. In this case, however, the difference in the rates of the two pendulums varies directly as the current, and the sum of these differences during the interval under consideration will be proportional to the quantity of electricity delivered.

The above result is approximate only, and the errors due to neglecting the term $\frac{K'^2}{8} . C^2.V^2$ will become of greater importance as the currents in the main coil become large. A more accurate result is obtained by fitting each pendulum with a pressure coil, and arranging the main current to influence both of them, so that the one is retarded and the other accelerated, when it will be seen that the effect of the term of the second degree is obliterated.

In this case, for the retarded pendulum $n_1 = n.(1 - K'.C.V)^{\frac{1}{2}}$, and for the accelerated pendulum, $n_2 = n.(1 + K'.C.V)^{\frac{1}{2}}$.

$$\therefore \qquad n_1 = n . \left\{ 1 - \frac{K'}{2} . C.V - \frac{K'^2}{8} C^2.V^2 - \frac{K'^3}{16} C^3V^2 - \ . \ . \ . \ . \right\}$$

$$n_2 = n \left\{ 1 + \frac{K'}{2} . C.V - \frac{K'^2}{8} C^2V^2 + \frac{K'^3}{16} C^3V^3 - \ . \ . \ . \ . \right\} .$$

The terms of the third degree and succeeding terms can be neglected, and

$$n_1 = n . \left\{ 1 - \frac{K'}{2} CV - \frac{K'^2}{8} C^2V^2 \right\} ,$$

$$n_2 = n \left\{ 1 + \frac{K'}{2} C.V - \frac{K'^2}{8} C^2V^2 \right\} .$$

$$\therefore \qquad n_2 - n_1 = n.K'.CV.$$

And in the same way as above,

$$\int_{T_1}^{T_2} C.V.dt = \frac{T}{K'} \int_{T_1}^{T_2} d(n_2 - n_1).$$

The results obtained for a gravity pendulum will also hold for any system having a simple harmonic motion, it only being necessary to substitute the law of force producing motion for that of gravitation.

Thermal Effect. –The heating effect of a current in a conductor is utilised in meters for special purposes only, mainly in maximum demand indicators, which serve to register the maximum current taken by an installation during a given period. If J denote the mechanical equivalent of heat, H the amount

of heat generated by the passage of a quantity of electricity Q, then, by Joule's law,

$$J.H = V.Q.$$

Assuming the current to remain constant during the time t seconds, and if V, C, and R be expressed in volts, amperes, and ohms, the heat developed in gramme-degrees Centigrade is given by

$$\begin{aligned} H &= 0{\cdot}238\ V.C.t, \\ &= 0{\cdot}238 \frac{V^2}{R}.t, \\ &= 0{\cdot}238\ C^2Rt, \end{aligned}$$

where $J = 4{\cdot}2$ joules or $4{\cdot}2 \times 10^7$ ergs.

Behaviour of Continuous Current Three-wire Energy Motor Meters.—The measurement of the electrical energy in continuous current multiple-wire systems presents no special difficulties when they are split up into a series of two-wire circuits, in each of which a two-wire meter is used. It is, however, not difficult to show, in the case of a three-wire system, that unless the two branches be perfectly balanced, *i.e.* equally loaded, and the pressures between the branches constant and equal, a three-wire energy motor meter will register incorrectly. If V_1 denote the pressure between the + outer and the neutral conductor, V_2 the pressure between the latter and the − outer main, and C_1 and C_2 denote respectively the currents in the positive and negative outers, V being the total voltage across the three-wire system, such that $V = V_1 + V_2$, then the power delivered is

$$P = C_1V_1 + C_2V_2,$$

and the energy consumed in the time $T_2 - T_1$ seconds is

$$E = \int_{T_1}^{T_2} V_1.C_1.dt + \int_{T_1}^{T_2} V_2.C_2.dt.$$

When both sides of the system are equally loaded, $V_1 = V_2 = \frac{1}{2}V$, and $C_1 = C_2 = C$ (say), when the energy becomes

$$E = 2\int_{T_1}^{T_2} V_1.C_1.dt,$$

or

$$E = \int_{T_1}^{T_2} V.C.dt.$$

In a watt-hour three-wire motor meter two main current coils are used, and the one coil is placed in series with the positive conductor and the other in series with the negative main, the armature circuit being energised by a current proportional either to the total voltage across the system, or to the pressure between either outer and the neutral wire. Assuming the pressure current to be due to V, the total three-wire voltage, then the energy registered by the meter is equal to $\frac{1}{2}.\int_{T_1}^{T_2} V.(C_1 + C_2)dt$. The power delivered to the total system is given by the equation

$$P = C_1.V_1 + C_2V_2,$$

and, however unbalanced the two branches may be,

$$V = V_1 + V_2,$$

hence $$P = V(C_1 + C_2) - V_2C_1 - V_1C_2.$$

By adding these two equations for the power, it follows that

$$2P = V(C_1 + C_2) + C_1(V_1 - V_2) - C_2(V_1 - V_2).$$

$$\therefore \quad P = \tfrac{1}{2}V(C_1 + C_2) + \tfrac{1}{2}C_1(V_1 - V_2) - \tfrac{1}{2}C_2(V_1 - V_2),$$

and $$E = \tfrac{1}{2}\int_{T_1}^{T_2} V(C_1 + C_2)dt + \tfrac{1}{2}\int_{T_1}^{T_2} C_1(V_1 - V_2)dt - \tfrac{1}{2}\int_{T_1}^{T_2} C_2(V_1 - V_2)dt.$$

If the system be in perfect balance, and also when C_1 and C_2 are unequal, but $V_1 - V_2$ is zero, the terms $\frac{C_1(V_1 - V_2)}{2}$ and $\frac{C_2(V_1 - V_2)}{2}$ will vanish, and the meter will register correctly. When the two branches are unbalanced, C_1 and C_2 being unequal, and also V_1 and V_2, the energy given by the three-wire meter, connected in the manner explained, will always be greater than that actually supplied, both when $C_2 > C_1$, as then $V_1 - V_2$ is positive, and when $C_1 > C_2$, as in this case $V_1 - V_2$ will be negative, so that the error is always of the same sign.

When the pressure circuit of the meter is connected between one outer and the neutral wire it will also register incorrectly, and will read high or low according as the voltage across the armature circuit rises or falls. This can be easily shown as follows:

$$P = C_1V_1 + C_2V_2.$$
$$V = V_1 + V_2.$$

Supposing the armature circuit to be energised by a current proportional to V_1, then

$$P = V_1(C_1 + C_2) - C_2(V_1 - V_2).$$

Therefore the true energy is

$$E = \int_{T_1}^{T_2} V_1(C_1 + C_2)dt - \int_{T_1}^{T_2} C_2.(V_1 - V_2)dt,$$

whereas the energy given by the meter is equal to $\int_{T_1}^{T_2} V_1(C_1 + C_2)dt$, which is less or greater than E according as $V_1 - V_2$ is negative or positive.

It follows from the above that with this second method of connection of the pressure circuit of a three-wire meter the actual error in any particular case is larger than with the armature circuit connected direct across the outer conductors, and the errors are not always of the same sign, but are positive or negative according as the voltage across the armature circuit is high or low.

NOTE.—In the Appendix at the end of the book will be found three tables (A, B, C) of percentage errors of continuous current energy motor meters corresponding to the above three cases. These errors can be readily verified from the formulæ stated above.

CHAPTER III.

CONTINUOUS CURRENT QUANTITY METERS.

Definition of a Quantity Meter—Classification of Quantity Meters—Advantage of the Quantity Meter—Wright Electrolytic Meter—Bastian Electrolytic Meter—General Description and Classification of Ampere-hour Motor Meters—Hookham Mercury Motor Meter—Ferranti Mercury Motor Meters—O'K. Meter—Electrical Company's Meter—Eclipse Meter—Hartmann & Braun Meter—Mordey-Fricker Oscillating Meter.

Definition of a Quantity Meter.—A quantity meter measures the amount of electricity in ampere-hours conveyed by the passage of a current flowing in a circuit, and, in general, is used on a practically constant potential continuous current system. When the supply pressure is constant the current is proportional to the watts, so that the measure of the ampere-hours becomes a measure, indirectly, of the energy in watt-hours. For electric lighting a quantity meter is invariably calibrated to register direct in terms of the supply unit of electrical energy, without the use of a multiplier or constant, at the supply voltage of the circuit to which it is to be connected. In this country the supply unit is the Board of Trade unit, and is equal to one kilowatt-hour, or 1000 watt-hours.

Classification of Quantity Meters.—Quantity meters may be divided into two classes, according to their principle of working, namely, electrolytic meters and electro-magnetic meters. The latter consist mainly of motor meters.

An electrolytic meter may be either of the shunted or unshunted variety. In the unshunted type the whole current to be measured flows through the electrolytic cell and decomposes the electrolyte, whereas in the shunted type practically the whole current of the installation traverses a low resistance with which the electrolytic cell forms a parallel circuit, so that only a fraction of the main current flows through it and effects the chemical decomposition. All electrolytic meters are based on the same principle. The rate of decomposition produced by the passage of a current in an electrolytic cell depends on the strength of the current; or, in other words, the number of grammes of metal deposited per second, or the number of cubic centimetres of gas evolved per second, is proportional to the current in amperes. Of the very numerous class of electricity supply meters of the electrolytic type, of which the Edison meter was the first to be commercially used, only the Wright meter and the Bastian meter are included in this chapter.

Advantage of the Quantity Meter.—The specific advantage of an ampere-hour meter is the absence of any shunt loss, which in the case of an energy meter is a continuous one whether the consumer be using current or not. This is a matter of considerable importance, especially in connection with

the supply of current at 200 to 250 volts to small consumers, many of whom take, on an average, less than a couple of amperes at their maximum load. Even for the registration of large currents, a watt-hour meter offers no advantage over an ampere-hour meter when the system is a constant potential direct current one, except on circuits subject to large voltage fluctuations. For the measurement of alternating currents, however, watt-hour meters are exclusively used, owing to the lag or lead of the current. It will be readily seen that with an average shunt loss of 4 watts in the pressure circuit of a direct current energy meter at 200 volts, the annual loss per meter is 35·04 B.O.T. units, which, at 1d. per unit generated and delivered at the consumer's terminals, represents an annual loss to the station of £146 per 1000 meters connected. This does not represent the total annual cost of the meters, as to this sum must be added the charges to cover depreciation, maintenance, and interest on capital outlay, which are greater for energy meters than for ampere-hour meters.

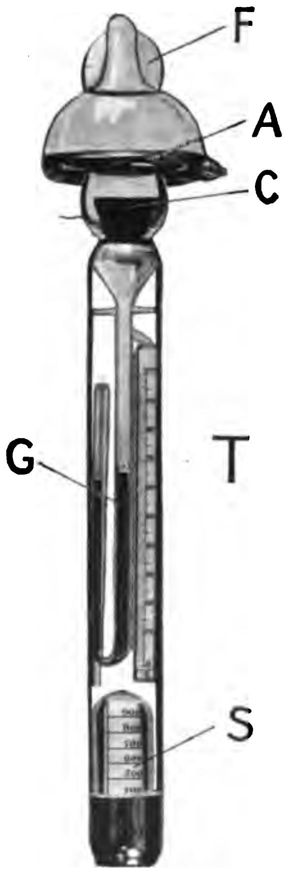

Fig. 1.

The Wright meter, made by the Reason Manufacturing Company, Brighton, is of the shunted type. The essential parts of the meter are the electrolytic cell, a fine wire resistance in series with it, and a low-resistance shunt, across the terminals of which the cell circuit is connected. The low-resistance shunt is placed in one of the supply mains, and the current through the cell is a very small fraction of the current to be measured, amounting to only a few milli-amperes. Fig. 1 represents the electrolytic cell of this meter. It consists of a solution of mercurous nitrate, a mercury anode A, and a platinum cathode C in the shape of a hollow cone. The mercurous nitrate solution practically fills the whole of the hermetically sealed glass tube T, except for two or three cubic centimetres of air to permit of expansion. On the passage of a current through the meter, the mercury is deposited in minute globules in the platinum cone and falls into the U-shaped syphon tube G, alongside which is fixed a scale graduated in units.

When a quantity of mercury calibrated to be equal to 100 units fills the U tube, its level in the first limb will be slightly above the top bend of the syphon. The whole of this mercury will be drawn over and will collect in the bottom of the sealed tube, which in this case is provided with a second 100 unit scale S.

By means of the anode feeder F the level of the mercury in the anode trough A is kept constant. A slight flow of mercury from the anode feeder to the anode takes place when any of the mercury has been electrolysed, whilst a corresponding amount of solution replaces the mercury thus withdrawn. The heavy solution formed at the anode falls, while the weaker

solution at the cathode rises, and the density of the electrolyte remains uniform. No differences of concentration exist, and, in consequence, the back E.M.F. is virtually negligible, not exceeding one ten-thousandth of a volt. The resistance of the cell is also constant. This result is accomplished by the automatic gravitational circulation of the solution, and by the action of the anode feeder in keeping the surface of the mercury of the anode always at the same height and of the same area. The meter is also compensated for temperature changes for a range of ten degrees Centigrade above or below the normal, as the fine wire resistance coil in series with the cell is so proportioned that its increase in resistance just counterbalances the diminution in resistance of the electrolyte with rise of temperature. The final adjustment of the meter is made by sliding the end wires of the low-resistance shunt up or down in the terminal blocks, thus varying the magnitude of the shunt resistance relatively to that of the cell circuit.

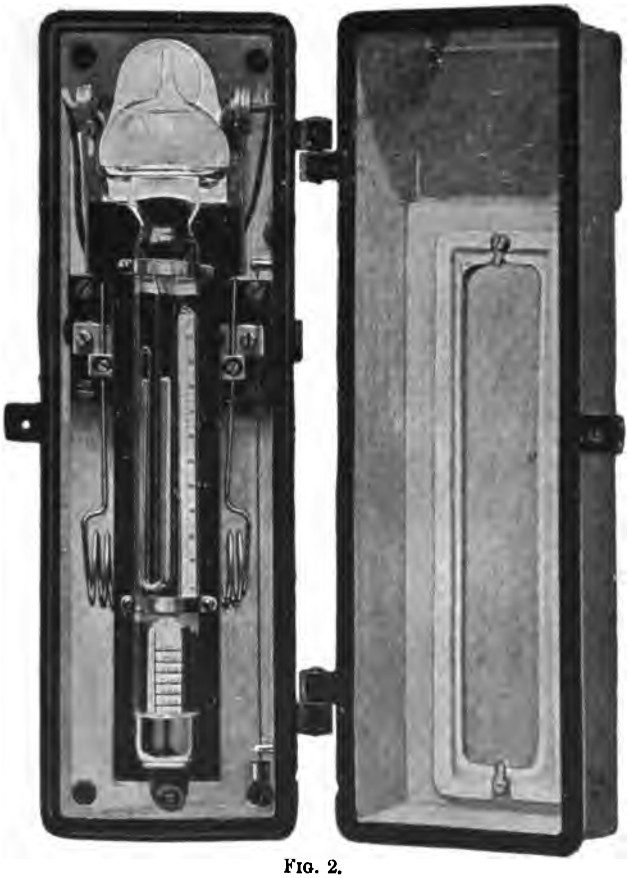

FIG. 2.

An illustration of the complete meter is given in Fig. 2, and represents the standard 10 ampere type, reading to 1000 units. It is enclosed in a strong cast-iron case, provided with a door having a window through which the scale can be read. When a meter has registered the maximum number of units marked on its scale, it must be re-set to zero. The method of re-setting the meter consists in tilting the whole tube about the hinged supporting brackets, so that the mercury gravitates back into the anode and feeder.

To reduce the adhesion of any mercury on the cathode to a minimum, the platinum cone is coated with finely divided metallic platinum precipitated from a solution of platinic chloride. The surface so coated is practically incapable of supporting any mercury globules. Difficulties arising from vibration are eliminated by supporting the whole of the anode mercury on a

cone of finely woven platinum gauze. This permits of free electrolytic action to the cathode, while the surface tension of the mercury prevents it from dropping through. The whole electrolytic cell is supported in its case on five spiral springs, to guard against jars and shocks.

For $2\frac{1}{2}$ up to 5 amperes the meter is furnished with a plain graduated tube which reads up to 250 units. Most of the defects inherent to electrolytic meters, especially of the shunted type, such as back E.M.F., varying proportionality between the shunt and cell circuit resistance, under-registration at low loads, temperature errors and large drop across the terminals, are eliminated in this meter, and a high degree of accuracy is attained. As the curve of the meter is practically a straight line, it is usual to test it at full load.

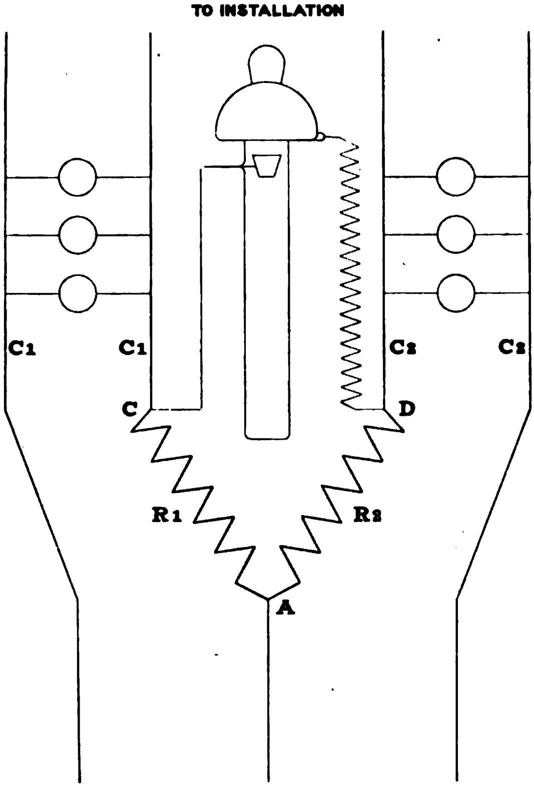

FIG. 3.

The balance between the magnitude of the fine wire resistance and the resistance of the electrolytic cell can be tested in two ways. Either a full load test is taken at a temperature differing from the normal by about 10 degrees, or the resistance of the electrolytic cell circuit is measured by a potentiometer at normal temperature and at some higher temperature. With the meter properly adjusted, no change in resistance will be obtained. The point at which the mercury syphons over, in the case of meters fitted with the second scale, can be checked by shaking over mercury until the mercury column stands at 97 or 98 on the unit scale, and then by passing current through the apparatus until the mercury goes over. The point at which this occurs should correspond to the hundredth division of the scale. The meter is readily adapted for use in three-wire installations, in which two distinct two-wire circuits are used. Fig. 3 shows diagrammatically the arrangement. The installation is divided into two approximately equal sections, the neutral wire being split into two branches.

At the point of junction A of these two branches, two low resistances R_1 and R_2 are inserted, of equal value. The current through the cell will be proportional to the sum of the currents C_1 and C_2 in the two halves of the

installation. This can be easily shown in the following manner. The difference of potential between C and D, to which points the electrolytic cell with its compensating resistance is connected, is $C_1R_1 + C_2R_2$, or when $R_1 = R_2 = R$ (say), this P.D. is $R\ (C_1 + C_2)$, and therefore the current in the cell is $\frac{R(C_1 + C_2)}{r}$, where r is the combined resistance of the cell and the compensating coil. Hence the current in the cell will be exactly proportional to the sum of the two currents, and the one meter will register the total energy supplied to the three-wire installation.

The Bastian Electrolytic Meter.—The Bastian ampere-hour meter, made by the Bastian Meter Company, is an unshunted electrolytic meter. It has the advantage of simplicity, and permanent accuracy when once calibrated, while it also registers with the smallest current. The general construction and arrangement of the latest type are shown in Fig. 4. It consists of two nickel electrodes inserted in a tube of uniform bore, which contains a solution of caustic soda. The top of the tube is closed by a porcelain cap, through which the rods of the electrodes project. These are joined by flexible insulated connections to the meter terminals, imbedded in sulphur in recesses cast on each side of the meter case. The scale reads direct in units, and can be slightly raised or lowered, so as to adjust the zero mark to the level of the electrolyte. A thin layer of paraffin oil rests on the top of the liquid column to prevent loss of water by evaporation or by the evolution of the gases on the passage of a current. The entire electrolytic apparatus is fixed in a cast-iron case, the bottom of the tube resting on an india-rubber cushion. The case is fitted with two covers, one of which has a window for reading the scale, and the other is to cover the terminals. In the older type of meter acidulated water was used as the electrolyte, and the electrodes consisted of platinum with lead leading-in rods. These constituents of the cell have now been abandoned owing to the large drop across the terminals which was obtained, amounting at full load to about 4 or 5 volts, and to the trouble experienced with the lead rods. By the use of the caustic soda solution and the nickel electrodes the drop does not exceed $1\frac{1}{2}\%$ at full load on a 200 volt circuit. As the current passes, the electrolyte is decomposed and the gases evolved pass off into the atmosphere. The difference in the height of the solution between two readings, as indicated by the scale, denotes the number of units consumed during the interval which has elapsed between the two readings. The reading is always taken at the junction of the oil film and the liquid. The Bastian Meter Company have obtained an almost black oil, which gives a much more defined line on the top of the water than ordinary paraffin oil, so that its use greatly facilitates reading the meter. In the action of the

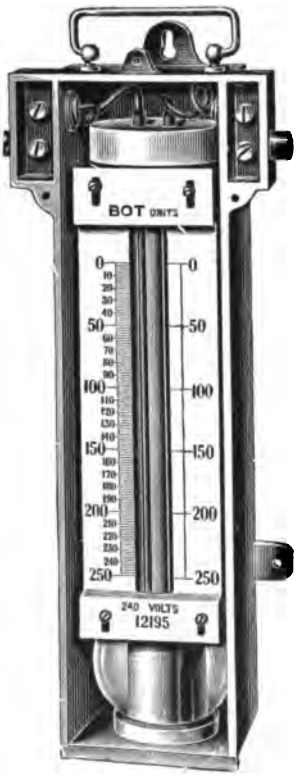

Fig. 4.

meter only the water is decomposed, and the specific gravity of the electrolytic solution increases towards the bottom of the scale. It is, therefore, only necessary to add fresh water periodically to fill the tube.

The graduations of the scale can be readily checked without passing current through the instrument. The tube is filled with water up to the bottom scale-mark after the electrodes are inserted. With a burette graduated in cubic centimetres, a quantity of water is then added equivalent to 10 or 20 units at the voltage for which the meter has been calibrated.

The level of the liquid column is noted, and should coincide with the corresponding scale division. By repeating this process the accuracy of the scale graduations can be determined.

General Description and Classification of Ampere-hour Motor Meters.—Motor meters form by far the largest class of electricity supply meters in commercial use. An ampere-hour motor meter has three essential parts—the motor, the brake, and the integrating mechanism. The motor consists of an armature which rotates in a magnetic field produced either by a permanent magnet or by an electro-magnet, usually in series with the armature. In both cases the current delivered to the installation flows either entirely or in part through the armature, which is connected to one of the supply mains. The motor drives the integrating mechanism and a brake, the function of which is to maintain a direct proportionality between the speed of the motor and the current flowing, so that the reading of the integrating train is proportional to the quantity of electricity delivered in a given interval of time.

When a permanent magnet is employed for the motor field, the driving torque is proportional to the current. In this case the retarding device consists of a copper or aluminium bell or disc, which is mounted on the armature spindle and rotates between the poles of the permanent magnet. The Foucault currents generated in the bell or disc exert a brake torque, which varies directly as the speed, so that when these two torques balance one another a direct ratio is obtained between the speed and the current.

If the magnetic field of the motor be due to an electro-magnet in series with the armature, the driving torque is proportional to the square of the current, and a brake system must be adopted such that the resisting torque varies as the square of the speed, as with air and fluid friction. It also follows, when balance occurs, that the rate of revolution of the armature is proportional to the current to be measured.

In all cases, however, due to solid friction, a straight line law between the current and the speed cannot be exactly obtained. By making the driving torque large and keeping solid friction—*i.e.* bearing friction, brush friction, and friction of the counting train and gear—as low as possible, the departure from the straight line law is slight, and will mainly be noticeable at low loads.

The integrating mechanism is a train of wheels fitted with index hands and dials, as in the ordinary gas meter type, or with rotating number drums or discs, the figures on which appear in line through slots in the dial face, and, in general, spring into position.

In every case the registration is given direct in Board of Trade units at the voltage of the circuit to which the meter is to be connected.

Ampere-hour motor meters may be divided into two classes—commutator motor meters and mercury motor meters. In the mercury motor meter no commutator and brushes are employed, the mercury bath accomplishing the same end, and in one of the types of the Ferranti meters the mercury constitutes, in addition, the armature of the motor.

The Chamberlain-Hookham Ampere-hour Meter.—The ampere-hour meter manufactured by Messrs Chamberlain & Hookham, Ltd., Birmingham, is in principle the same as a small series motor with permanent magnets. The driving torque is proportional to the current to be metered, and the work done is dissipated in Foucault currents proportional to the speed. A section of the instrument is given in Fig. 5, showing in detail the construction of its constituent parts.

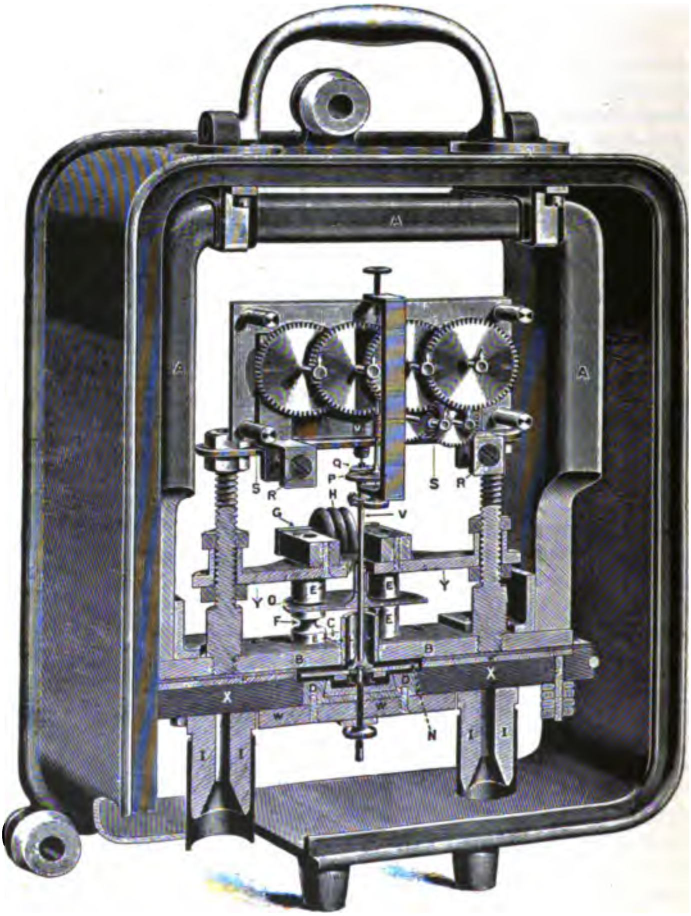

FIG. 5.

The permanent magnet consists of a single bent bar A A of tungsten steel, mounted vertically on soft iron plates B B, and separated in the middle by a brass piece C. E E are the brake pole-pieces, and D D is the circular iron bridge-piece forming the lower half of the mercury chamber L L, in which the armature N is immersed and partially floated. The magnetic circuit of the brake field is completed through the air-gap in which the aluminium brake disc O rotates, the upper pole-pieces E E, and the bridge-pieces G. The lines

of force constituting the driving field of the meter pass from the one soft iron plate B vertically downwards into the mercury chamber, cutting the armature disc; they then traverse the iron bridge-piece D D, and re-enter the mercury chamber vertically upwards, again cutting the armature disc, and finally leave by the other iron plate B. An intense magnetic field is produced at B D in this manner, and is cut twice by the armature disc in opposite senses.

The armature consists of a copper disc, slit radially, and amalgamated on the rim so that current can only flow diametrically across it, and is con-

Fig. 6.

centrated within the area beneath the brake pole-pieces. To prevent amalgamation with the mercury, the upper and lower surfaces of the armature disc are suitably protected.

I I are the two main current terminals, and K K are insulated copper strips terminating in the mercury, which is insulated from the other parts of the containing vessel. The current to be metered enters the mercury by the copper strip connected to the + terminal and leaves the instrument by the − terminal after flowing through the armature and round the series coil H. This coil compensates for the increase of fluid friction with increase of speed on the high loads by weakening the magnetic flux cutting the brake disc. It does not affect the driving torque on the armature disc, but only acts upon the

brake field. The effect of this coil can be altered by adjusting the bridge-piece G on which it is mounted, and this adjustment can be used for altering the constant of the meter at the high loads; it will not produce any appreciable effect on light loads. The adjustment of the brake torque relatively to the driving torque is carried out by raising or lowering the arm Y carrying the brake pole-pieces.

By means of the reduced neck at F of one of the brake pole-pieces, and by the use of the soft iron plates and bridge-pieces, the magnetic fields are

FIG. 7.

kept constant, and remain unaffected by any diminution in the magnetism of the permanent magnet. The weight of the rotating element is mainly carried by the mercury, with the result that friction on the bearings is very small. The meter stands on an ebonite base X X, and is enclosed in a cast-iron case of strong mechanical construction. For transit the armature spindle V is lifted off the lower jewel and clamped against the upper spring guide-bearing by the stop-screw in front of the instrument, the latest type of which is illustrated in Fig. 6.

The revolutions of the armature spindle are transferred to the index train,

the dials of which indicate direct in B.O.T. units at the voltage at which the meter is calibrated. The index hands on the dials can be easily detached and placed at zero, to facilitate testing and setting. Each meter is supplied with a meter constant, giving the time in seconds per revolution of the armature per ampere, and this can be readily checked by sending a suitable current through the meter and noting the time taken by the brake disc to make a given number of revolutions. The integrating train is removed by unscrewing two bolts, when another spindle with a different ratio wheel and worm can be inserted in it, which forms the usual alteration necessary to adapt the meter for use with a different voltage.

To meet the demand for a cheap but reliable meter for the registration of small currents, this company supply their 1902 type for 1½ up to 5 amperes. The principle of working is the same as in the large type just described, the meter differing from it in constructional design only. The armature consists of a cylindrical copper bell rotating in an annular chamber filled with mercury. The chamber is formed by the poles of the permanent magnet and an ebonite block in which the poles are partially imbedded. The current of the installation is led into and out of the mercury chamber by means of two conductors, of which the one is connected to the top of the chamber and the other to the underneath portion and on the same side. The current thus flows down one side of the armature only, and the electro-magnetic action between it and the strong magnetic field between the poles of the permanent magnet causes it to rotate. The same field is utilised to produce the brake torque by means of the eddy currents generated in the revolving copper bell.

A compensating coil in series with the armature is also used to compensate for the error at high loads, due to increased fluid friction. It is wound on an iron core placed as a shunt to the poles, and is in the front of the meter, a view of which is given in Fig. 7. The action of the coil is to divert a portion of the field from the poles of the permanent magnet to the core. In this manner the permanent magnet is shielded also from the effect of a short-circuit current. The adjustment of the meter on the high loads is made by the aid of the compensating coil, which is wound in sections. Either the whole coil or one or more of the sections can be used, and in this way its effect correspondingly varied.

The Ferranti Meter.—The Ferranti ampere-hour meter is in reality a series motor of the unipolar type, and is shown in section in Fig. 8, which represents a 10 ampere size. The magnetic field is produced by a cylindrical electro-magnet, having inwardly projecting steel poles. The series coil C C is mounted on the steel pole S P, and is connected to the negative meter terminal marked T –, which is insulated from the magnet, and to the iron ring I R. This ring embraces the poles, and forms with them an annular chamber, which is filled with mercury. The mercury bath M B is insulated on the top and the bottom by means of fibre, and constitutes the armature of the motor.

To prevent over-magnetisation due to an excess current through the meter, a soft iron sleeve S is slipped over the steel pole, which is magnetised to a certain degree for the meter to start with small currents.

Prior to the use of the iron sleeve, the effect of a short-circuit current was to over-magnetise the steel pole and cause the meter to run light and too fast on low loads. The brake system consists of a light fan of four vanes, immersed in the mercury, and mounted on a vertical spindle. The spindle runs in a jewel bearing, with, however, an extremely small amount of friction, as the weight of the revolving element is mainly borne by the mercury.

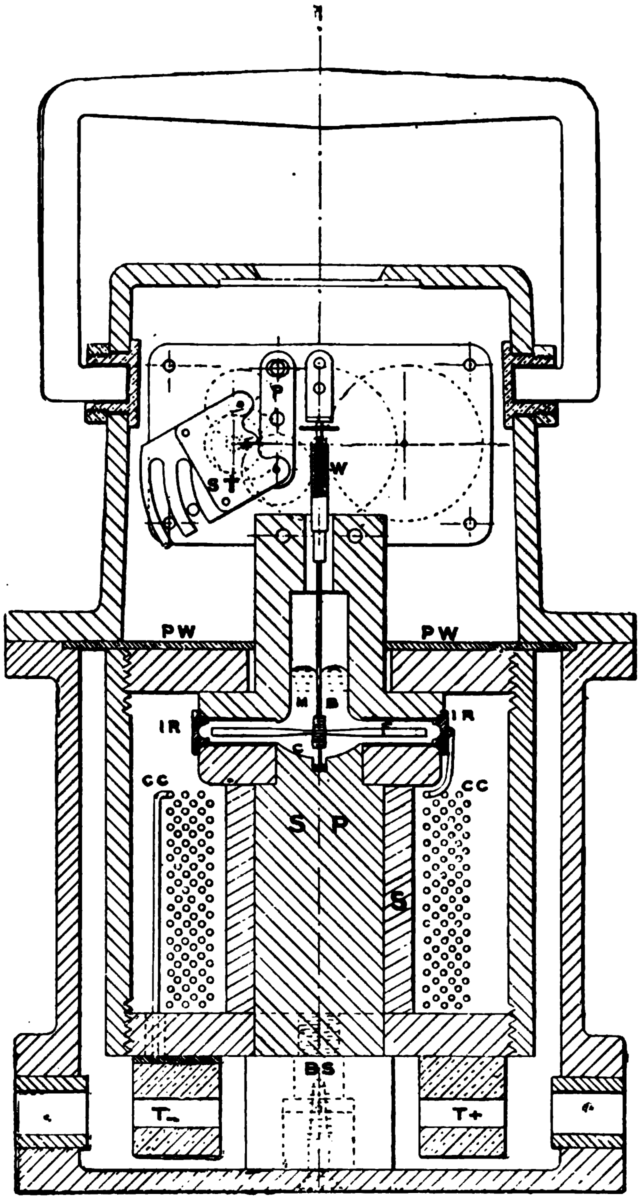

Fig. 8.

The current enters the meter at the positive terminal marked T +, whence it traverses the pole S P and passes into the mercury at the contact C. It then

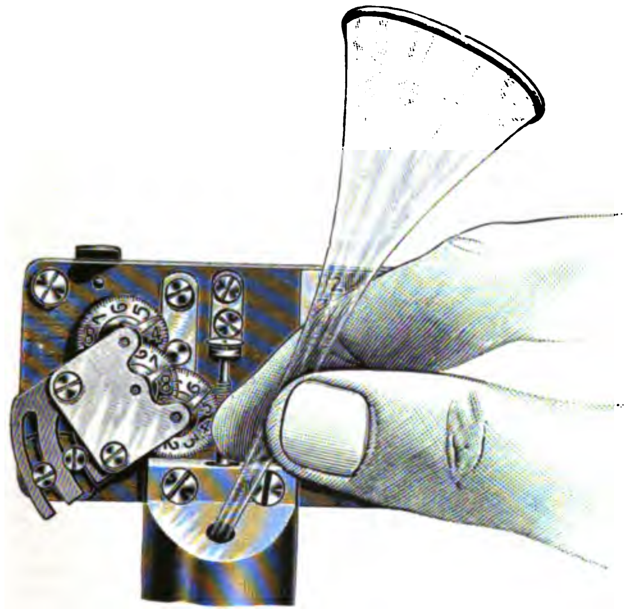

FIG. 9.

flows radially through the mercury to the iron ring, circulates round the series coil, and leaves by the negative terminal.

The electro-magnetic action between the magnetic field of the electro-magnet and the current in the mercury causes the latter to rotate, and with it the brake fan and spindle.

The driving torque is in this case proportional to the square of the current, and the resisting torque due to the fluid friction on the fan is proportional to the square of the speed, so that when balance ensues, neglecting friction, the speed is directly proportional to the current flowing. The manner in which the revolutions of the meter spindle are conveyed to the integrating train will be understood by reference to Fig. 8 and Fig. 9, the latter of which is an illustration of the swing train at the back of the meter dial. The worm W on the meter spindle drives a swing train S T, which carries on its last spindle a ratio pinion, gearing with the ratio wheel on the first spindle of the index train. Fig. 10 is a view of the back of the front train, with the swing train removed,

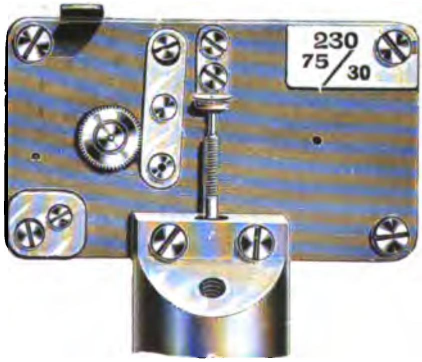

FIG. 10.

showing the ratio wheel, the top jewel bracket, and the swing plate. By means of this plate, which carries the swing train, the first wheel can be adjusted to gear with the worm on the spindle.

The high-load adjustment and the adjustment for different voltages are carried out by altering both the ratio wheel and the pinion. For this purpose the meter is provided with a complete set of these wheels and pinions. Particulars of the ratio wheel and pinion, and of the voltage for which the meter has been calibrated, are marked on the back of the dial, as will be seen from Fig. 10. The wheels of the swing train have numbers marked on them, by means of which the revolutions of the meter spindle can be read off, and a quick and reliable test made of the meter constant. A front view of the complete instrument is given in Fig. 11, from which its sound mechanical construction will be readily seen. It is enclosed in a strong cast-iron case, which is divided into two chambers, separated by a thick presspahn washer. The upper chamber encloses the counting train, and is provided with two windows, one in front for reading the dials, which indicate direct in Board of Trade units, and the other at the back for counting the revolutions of the spindle on the swing train.

Fig. 11.

The meter has to be filled with mercury before it is placed on circuit. The top cover is first removed, then the mercury screw is taken out of the hole on the top of the train support, to be seen in Figs. 9 and 10, when the proper amount of mercury, provided with each meter, is poured in through a glass funnel.

Messrs Ferranti, Ltd., have just recently introduced a new continuous current ampere-hour meter of the mercury motor type, but differing in many essential details from the one just described. The general construction and working of the meter will be understood by reference to Figs. 12 to 15. The armature in this case consists of a platinum-plated copper disc C D, immersed in the mercury bath M B, formed by the two nickel-plated brass plates B P and the fibre ring F R. The plates B P are suitably insulated from the mercury on their internal surfaces by the presspahn insulation P I. The edge and centre of the copper armature disc are amalgamated, so as to ensure that the current passes through the disc from the copper contact C_1 to the second copper contact C_2. The armature is mounted on the steel spindle S, which runs in a removable cup jewel J, and drives the integrating train through the worm wheel W W and a variable wheel gear. The armature is weighted by means of the weight W so that the disc just sinks in the mercury, considerably reducing the pressure and

friction on the lower jewel, and the balance of the disc is adjusted by means of the three small nuts N.

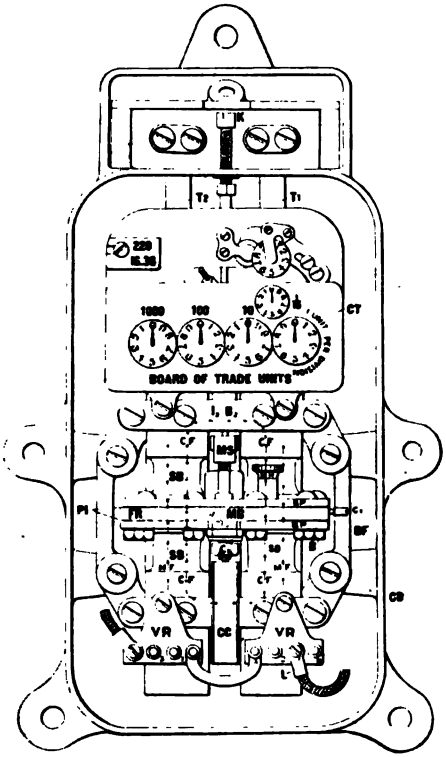

FIG. 12.

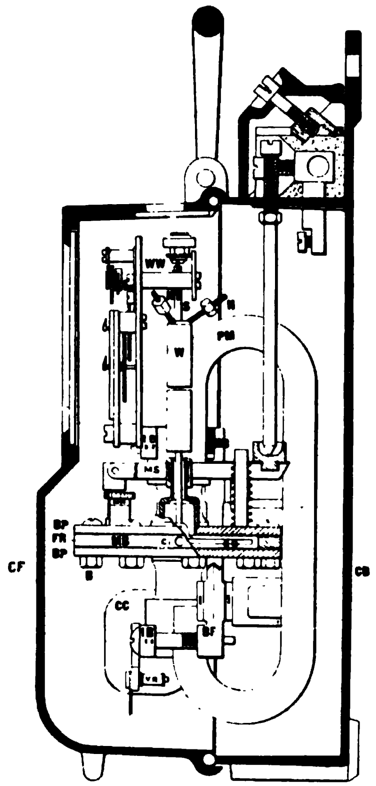

FIG. 13.

Two permanent magnets P M and two pairs of poles S D and S B are used, the former pair producing the driving torque on the disc when current flows through the latter, and both pairs of poles produce the retarding torque proportional to the speed. The current to be measured flows from the positive terminal T_1 to the copper contact C_1, from which it enters the mercury bath and flows through the armature disc, cutting the lines of force due to the driving poles S D, and leaves again by the second copper contact C_2 in series with the compensating coil C C and the negative terminal T_2. The rotation of the disc between the two pairs of poles sets up Foucault currents in the disc, which, reacting with the magnetic fields of the two pairs of poles, produce the brake torque proportional to the speed. When balance occurs between these two

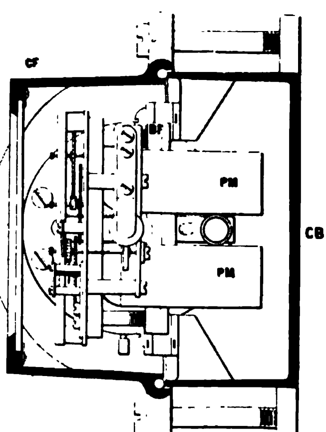

FIG. 14.

torques, neglecting solid and fluid friction, *i.e.* when the condition of steady motion is reached, the speed is proportional to the current. At high loads, however, this proportionality between the speed and the current will be destroyed, owing to the mercury fluid friction, which causes the meter to run slow at the higher loads. To compensate for this disturbing effect, the compensating coil C C, already referred to, is used, and is traversed by the main current flowing. It is carried on the lower iron bar $I_1 B_1$, which unites the bottom poles together. The top poles are also joined through the upper iron bar $I_2 B_2$. The coil is so wound that the lines of force (Fig. 12) produced by the current flowing go in the direction indicated by the arrows C F. This flux increases the magnetic field in the driving poles S D, and decreases the magnetic field in the retarding poles S B of the permanent magnets, the fields of which are shown by the arrows M F. It will be remembered that both pairs of poles retard the disc; and since the flux of the one is increased and that of the other is decreased, the total retarding torque remains the same with or without the correcting coil. The driving torque is, however, increased at the high loads, so that the disturbing effect of fluid friction is rectified.

FIG. 15.

The meter is made, as explained above, for sizes from 3 up to 100 amperes, but for larger capacities is supplied with a suitable shunt. A small adjustment of the constant of the meter is provided by means of the variable resistance V R (Fig. 12), connected as a shunt to the meter. It has six terminals. By connecting the lead L to the terminals from 0 to 5, from 0 to 5 per cent. of the current is shunted from the mercury bath, and a speed reduction up to 5 per cent. can be obtained. By means of this resistance a simple adjustment of the meter to a few per cent. is obtained without the necessity of removing the existing ratio wheels and the fitting of others.

Referring to the figures, the mercury is poured into the trough through the hole M H, which afterwards is closed with a screw, and the mercury chamber

is sealed, for transit or handling, by turning in a clockwise direction the knob K (Fig. 12).

The elements of the meter are enclosed in a strong cast-iron case, and the terminals are arranged at the top of the instrument. The terminal chamber is separately sealed, and gives access to the mercury sealing-knob K without the necessity of opening the main meter case. The mechanical design, characteristic of the Ferranti meters, will be readily followed from the illustrations.

The meter is very quickly tested, as the front dial has a $\frac{1}{10}$ unit circle, and there is also a small wheel with graduations on its edge, by which readings can be taken of $\frac{1}{100}$ of a unit. This wheel is readily visible through the front meter window, and is clearly shown both in Fig. 12 and in Fig. 15, which is a front view of the complete meter with the cover and terminal door removed.

The O'K. Meter.—An extremely simple ampere-hour motor meter, with an electrical efficiency of very nearly unity, is that invented by O'Keenan, of Paris, and known as the O'K. meter. In this case the motor does no outside work beyond driving the integrating train and overcoming the very small amount of friction in the bearings, the armature being accelerated on the passage of a current in the circuit to which it is connected until the counter and applied electro-motive forces across the brushes are equal, when the speed remains steady, provided the current does not vary. The speed of rotation is then proportional to the potential difference across the terminals. The O'K. meter is manufactured by the Compagnie pour la Fabrication des Compteurs, Paris, the Danubia Actiengesellschaft, Vienna, and by the British Thomson-Houston Company, Rugby. The main difference exists in connection with the commutator and brushes, which are of silver in these meters of the French and German companies, whereas the British Thomson-Houston Company use gold commutator segments and gold-tipped brushes. Fig. 16 is a view of the O'K. meter of the last-named company.

FIG. 16.

A strong permanent magnet is used having a stationary core of soft iron, supported on a bracket between the poles of the magnet. The armature rotates in the air-gap between the poles and embraces the fixed iron core. It is former wound and connected to a four-part commutator. The whole revolving element is mounted on a vertical spindle, which runs in a sapphire jewel supported in a spring-seating in the jewel screw. The spindle is guided at the upper end, and drives through a fine worm the integrating train. On the right of the motor is a low-resistance shunt, to the ends of which the brushes are connected. This shunt resistance is joined to the terminals of the meter, and is placed in series with one of the mains to the consumer's circuit. No brake or resisting device is employed. The current flowing in the installation to which the meter is connected divides in the meter into two

parts, of which the one flows through the shunt and the other through the armature of the motor. When the circuit is closed the armature begins to rotate, and its speed increases until the back E.M.F. of the revolving armature counterbalances the potential difference at its terminals. When this condition is reached, only so much current flows through the armature as is necessary to overcome the frictional resistances to motion, which are reduced to a minimum. The speed of the motor is therefore proportional to the P.D. across the shunt resistance, and consequently to the total current flowing. Practically the whole current passes through the low-resistance shunt, as the current in the armature is almost negligible, and any alterations in resistance of the armature circuit will not influence the indications of the meter, which is therefore independent of temperature variations. It is also uninfluenced by short-circuits. The commutator and brushes are arranged at the bottom of the meter, and, together with the lower jewel-bearing, are protected by a separate cap, fixed to the main meter cover by a bayonet catch. These parts are thus readily accessible for inspection and cleaning. The general appearance of the meter with the case on will be seen from Fig. 17.

FIG. 17.

The speed of the meter is regulated at full load by altering the position of the sliding contact of the low-resistance shunt in series with the main circuit. The meter is usually made for small currents up to fifteen amperes. The Compagnie pour la Fabrication des Compteurs, Paris, however, adapt it for use on circuits taking up to 100 amperes, by compounding it with a pressure circuit consisting of a high resistance placed across the supply mains, and producing a constant small extra potential difference between the brushes of the armature. The method they employ will be understood by reference to the diagrammatic sketch in Fig. 18, in which the meter is shown placed in the positive side of the circuit. With the connections as shown, the potential of the left-hand brush of the armature A will be higher than that of the right-hand brush, and the armature will rotate from left to right on the passage of a current through the low-resistance shunt R in series with the positive main. On light loads there will, however, be a tendency to run slow, as it is not possible to eliminate all the frictional disturbances to motion. If, on the other hand, by some means a potential difference is

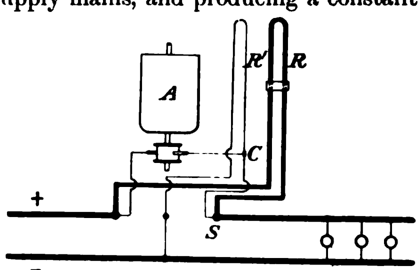

FIG. 18.

established between the brushes, which will produce a current in the armature just sufficient to give the necessary torque to overcome these frictional resistances, the torque and accuracy of the meter will be considerably increased, and its curve rectified at this end. This result, as already mentioned, is obtained by inserting a high-resistance R′ between the right-hand terminal S and the negative main, and connecting the right-hand brush to an intermediate point C of this resistance. The current which traverses this high-resistance pressure circuit is only 0·01 ampere, so that the watt loss is low, being 1 watt per 100 volts.

The constant drop across S C produced in this way is added to the drop across the low resistance through which the main current flows, augmenting the P.D. across the brushes of the motor.

The high-load adjustment is made by altering the position of the sliding contact on the low resistance, and the friction compensation at light loads, that is, at about $\frac{1}{20}$ full load, is carried out by increasing or decreasing the

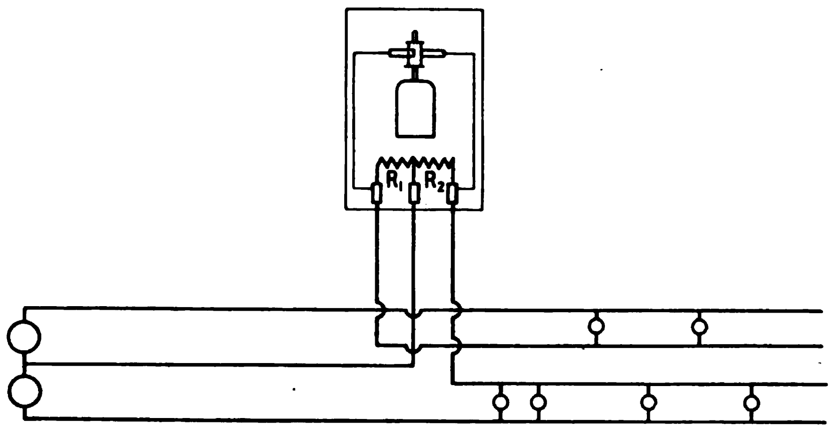

Fig. 19.

portion S C of the pressure circuit between the right-hand terminal S and the right-hand brush, according as the meter is running slow or fast. Increasing this portion will raise the P.D. across the brushes, and therefore augment the speed of the armature.

In Fig. 19 is shown a diagram of the arrangement of the O'K. meter when used by the British Thomson-Houston Company for a three-wire circuit.

The meter is provided with two low-resistance wires R_1 and R_2, in series with one another, and having their extremities connected to the armature brushes.

The common junction of these two resistances is joined to the middle terminal of the meter, to which the neutral wire is brought, and each resistance carries the current in that half of the system to which it is connected. The speed of the armature depends on the sum of the potential differences between the common junction and the ends of the two resistance shunts, and the meter correctly registers the ampere-hours or watt-hours delivered to the three-wire circuit, irrespective of the loads of the two sides.

The O'K. three-wire meter of the Compagnie pour la Fabrication des

Compteurs, Paris, consists practically of two two-wire O'K. meters combined to form one instrument. The two armatures rotate between the upper and lower pole-pieces of two permanent magnets, and each is connected across the ends of a separate low-resistance shunt, the right-hand resistance connected to the upper O'K. armature being clearly visible in the illustration of their three-wire meter given in Fig. 20. Each resistance is traversed by the current in one of the outers of the three-wire circuit, and the speeds of rotation of the armatures are respectively proportional to these two currents. The two armatures are mounted on separate spindles, and each armature spindle drives through a differential gear the one counting train of the meter, which registers the number of ampere-hours or watt-hours consumed in the two branches. Electrically, the two portions of the meter are quite independent of one another, which is an important feature, as, in consequence, the same accuracy can be obtained on each of the two sides of the system whether they are equally or unequally loaded. The meter is compact, light, and has no shunt loss. Fig. 21 shows diagrammatically the method of connection to be used. This meter is also used by the British Thomson-Houston Company.

Fig. 20.

The Electrical Company's Ampere-hour Motor Meter.—The ampere-hour motor meter of the Electrical Company, Limited, London (manufactured by the Allgemeine Elektricitäts-Gesellschaft, Berlin), differs from the O'K. meter in that the motor does work in the generation of eddy currents by driving a magnetic brake. For the general arrangement of the meter, type RA, front view of the instrument, see Fig. 22.

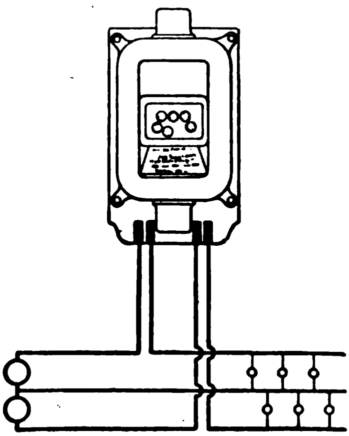

Fig. 21.

The magnetic field, which acts both as a driving and a brake field, is produced by a powerful permanent magnet, having between its poles a stationary soft iron core. The armature is connected to a three-part silver commutator, and rotates in the air-gap between the soft iron core and the pole-pieces. It is former wound with fine wire, and the windings are placed on a light aluminium cylinder, which acts as the brake. The brushes are composed of silver wire, and are connected to the ends of a shunt consisting of low-resistance wire or metal strip, which is traversed by the main current

taken in the installation. On the passage of a current through the shunt, a potential difference, amounting to one volt at full load, is established across the brushes, and the motor runs up to speed until the brake torque due to the eddies induced in the armature cylinder balances the driving torque, when the speed is proportional to the current to be measured.

The spindle carrying the armature and commutator runs in a ball step-bearing, flexibly supported, and drives through a worm near its lower end a cyclometer counting-gear, the figures of which spring into position and read direct in Board of Trade units. The special ball-bearing and cyclometer counter used by this company in their motor meters are described in Chapter XIII. When a decimal portion is included on the counter, the figures

FIG. 22.

are usually, as in most other types, coloured red, to distinguish them from the unit portion.

The calibration at full load is proceeded with, as in the O'K. meter, by adjusting the position of the movable contact on the resistance wire in the front of the meter.

The Eclipse Ampere-hour Meter, type CR, manufactured by The Luxsche Industriewerke, Munich, Germany (G. Braulik, London), also comprises a small electro-motor with a magnetic brake. The meter, with the cover removed, is shown in Fig. 23. Two permanent magnets, oppositely polarised, are used in this case to produce the magnetic field. The armature (Fig. 24) consists of three flat elliptically-shaped coils, A, B, and C, which are carried on a light aluminium disc D. The latter constitutes the magnetic brake,

having eddies induced in it by its rotation in the magnetic field. The coils are connected together to form a triangle, each corner of which is connected to a silver segment of a three-part commutator on which the brushes bear. Two coils are always in series with one another and in parallel with the third, and the effect of the one group is added to that of the other, as the two permanent magnets have opposite polarities. The two brushes are connected in parallel with a low-resistance wire, which is traversed by the current to be metered. Each brush is composed of two fine silver bands, which are held with their edges on the commutator by means of a light steel spring.

FIG. 23.

The speed of the disc is regulated at full load by moving the adjustable bridge-piece on the resistance wire, and so altering the current in the armature coil, which is a fraction of the main current.

A cyclometer counter, driven by the worm on the meter spindle, integrates direct in units the energy consumed.

The whole revolving element (Fig. 24) is very light, and the spindle runs in a spring-borne jewel, no locking device being employed for transit. By the employment of a three-part commutator, brush friction is considerably minimised, as in the case of the Electrical Company's meter.

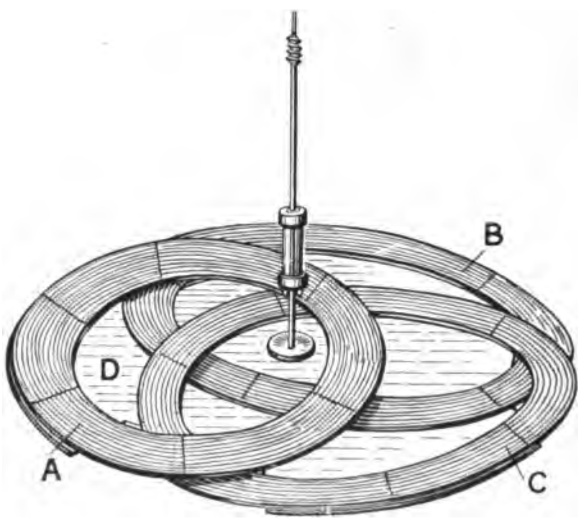

FIG. 24.

Hartmann & Braun Ampere-hour Meter.—Messrs Hartmann & Braun, of Frankfort (the Union Electric Co., London), manufacture a very interesting and novel ampere-hour meter, in which only one brush is used in conjunction with a three-part commutator.

The armature consists of three flat coils mounted on a light aluminium disc

which rotates between two vertical horseshoe magnets, with their opposite poles facing one another.

Each coil is divided into two parts, arranged on the aluminium disc at the opposite ends of a diameter, and they are so connected, either in series or in parallel, that the fields they produce are opposed. With this arrangement the meter will start whatever the position of the armature, and is unaffected by external fields, on account of the strong permanent field it possesses, and because the lines of force due to the armature coils run parallel to the axis of rotation.

Fig. 25 is a diagrammatic representation of the armature system. A A′, B B′, and C C′ are the three coils; they are connected together at one end, and each coil is in series at its other end with a commutator segment and

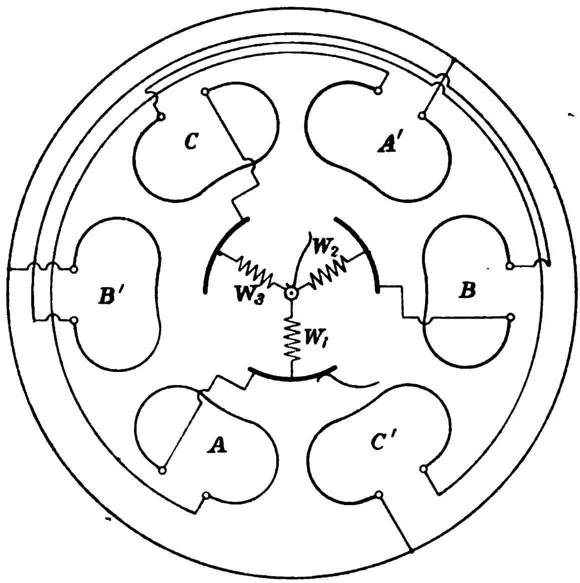

FIG. 25.

one of the resistances W_1, W_2, and W_3. The three resistances are connected together on the armature shaft.

The construction of the meter is illustrated in Fig. 26.

The permanent magnetic field is produced by two U-shaped magnets, which are secured to the cast aluminium base-plate of the meter, so that no possible alteration of the air-gap between their poles can take place.

In addition to the flat coil system, commutator, and worm-wheel, the spindle carries the three small resistance coils of the armature circuit, which is branched off a low-resistance shunt mounted at the back of the base plate. This shunt is placed in series with one of the supply mains.

A light spring bears on the rounded top of the armature spindle and serves to convey the current to the armature, from which it is conducted by the one brush on the commutator. The aluminium disc forms with the permanent magnet the magnetic brake of the meter, and the revolutions of the disc are

transferred in the usual manner to a counting mechanism with springing figures.

The instrument is mainly intended for the registration of small currents. A noteworthy feature is the improved construction of the commutator, whereby all disturbing influences arising from dust and sparking can be avoided. The different segments are not mounted in the ordinary way, but each one is arranged below the other, giving a large air-space and securing a high insulation.

1:3

Fig. 26.

The Mordey-Fricker Ampere-hour Meter, manufactured by the British Insulated Wire Co., Ltd., Prescott, is based on the electro-magnetic effect of a current, but differs from all other types of this class in being an oscillating meter of a special kind. It is a simple clock, the rate of which is controlled by the current in the circuit, and which stops when no current is passing. The ordinary hairspring of the balance-wheel of the clock is replaced by a disc of slate, on which are fixed a few iron wires.

The disc is mounted on the balance-wheel shaft, and is symmetrically supported between two coils, which are traversed in series by the current to be measured.

The current in the coils produces a magnetic field, which acts on the iron wires in the same manner as an ordinary galvanised needle, magnetising them, according to the strength of the current, to a greater or less extent, and causing the disc to swing more or less rapidly into a central or axial position between the two coils. In conjunction with the action of the mainspring of the clock, the disc, and with it the balance-wheel, will oscillate at a rate proportional to the current in the installation.

The coils thus act as a variable hairspring, and the clock, on the passage of a current, goes, and at a rate dependent on the strength of the current.

The revolutions of the clock are transferred to a cyclometer or to a dial counter, which is geared to indicate directly the consumption in Board of Trade units for constant pressure circuits. The meter, which is illustrated

in Fig. 27, is primarily intended for the registration of small currents, and readily starts with one 8 c.p. lamp at 250 volts. It can be used for either direct or alternate current circuits, and is independent of frequency for the periodicities met with in practice. The clock is provided with an ordinary eight-day movement, and only requires to be wound up once every quarter, as

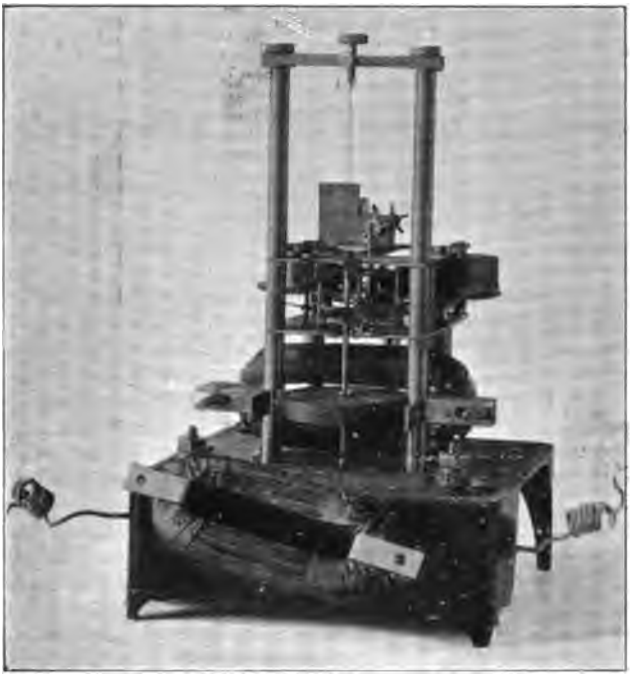

Fig. 27.

on small installations, for which it is intended, its average speed is very slow, and, moreover, it does not go when the current ceases. The balance-wheel shaft moves in a footstep jewel, and is, further, sometimes suspended by a torsionless silk fibre, attached to it by a bent wire spring. The object of the silk suspension is to relieve the jewel of the weight of the shaft balance-wheel and disc, and so safeguard it from damage.

CHAPTER IV.

CONTINUOUS CURRENT ENERGY MOTOR METERS.

General Description—Thomson Meter of the British Thomson-Houston Co.—Thomson Meter of the General Electric Co., U.S.A.—Duncan Meter—Vulcan Meter—Eclipse Meters—Meter of Mix & Genest, Berlin—Siemens-Schuckert Meters—Elimination of Friction—Evershed Frictionless Motor Meter—Hartmann & Braun Motor Meter.

General Description.—Continuous current energy motor meters depend on the well-known electro-dynamometer principle, in which the electro-magnetic action between the currents in a stationary coil and a movable one produces motion in the latter. This motion, in the case of motor meters, is converted into one of continuous rotation by the aid of brushes and a commutator electrically connected to the moving coil and carried on the same spindle.

All motor meters consist of three essential parts, which are the motor, the brake system, and the integrating mechanism. The motor, in all the meters included in this chapter, contains no iron in either the armature or its field system. The field or main current coils are stationary, and are connected in series in one of the supply mains for a two-wire meter. The armature is composed of fine wire coils placed as a shunt circuit across the supply leads.

The field coils are, therefore, traversed by the whole current taken by the particular installation in which the meter is fixed, whereas the armature is energised by a current proportional to the supply pressure. A high resistance is also used in the pressure circuit in series with the armature, to keep the pressure current low and to reduce the voltage across the brushes. The current in the main or series coils sets up a magnetic field which is proportional to the number of amperes in the main circuit, and the current in the armature produces another field of force, at right angles to that of the series coils, which is proportional to the voltage.

These two magnetic fields exert at every instant a driving torque on the armature, which is proportional to the product of both fields, that is, to the product of the P.D. and the main current flowing, or to the actual power supplied in watts.

The brake system is to absorb the work done by the motor, and must be such that the retarding torque which it exerts is at every instant proportional to the speed of the armature. This result is obtained by rotating a non-magnetic metal disc, mounted on the armature spindle, between the poles of one or more permanent magnets.

The portion of the disc embraced by the poles cuts the lines of force of the brake field at right angles, and at a rate depending on the number of revolutions of the armature spindle, and the Foucault currents generated in the disc will vary in intensity as the speed.

The resisting torque is at any moment proportional to the product of the

brake field of the permanent magnets and the strength of the induced currents, and, therefore, to the speed. When steady motion has been established, the driving and retarding torques will balance one another, neglecting all frictional resistances, and the speed will vary directly as the power supplied. The number of revolutions made in a given time will then be proportional to the energy consumed in this period. It must be remembered, however, that the assumption is made that the various frictional resistances which occur in a meter are negligible.

These frictional resistances are—(1) friction of axle bearings, (2) friction of brushes on the commutator, (3) air friction, and (4) friction of the counting train and gear connecting it to the motor spindle.

Generally, friction is considerably reduced, and in a well-designed meter does not influence its indications at high loads, being mainly noticeable at low loads. The matter is complicated still further, as friction is not constant at these low loads, but is a variable quantity. It may be mentioned here that air friction is so slight that it is entirely neglected.

To compensate for the frictional resistances, and to enable the meter to readily start with a small current when the magnetic effect of the main current coils is weak, a compound or auxiliary winding is used. This compensating coil consists of a few turns of wire in series with the armature circuit, and is placed relatively to the main current coils, so that the lines of force it produces augment the main field. At these very low loads the magnetic field of the main current coils is so weak that the torque exerted is, unaided, insufficient to overcome the forces of friction. The additional torque is supplied in the manner just explained. It will be seen that this supplemental field is always present, as the pressure circuit is always energised. Moreover, the compound winding becomes relatively of less importance as the load on the meter increases. The compensating coil is usually made adjustable, so that its distance to or from the armature may be varied to suit the immediate conditions of the installation. It is generally so adjusted that the meter starts with a current between 1% and 2% of the maximum capacity of the installation.

The registering or integrating mechanism is an ordinary train of wheels and pinions gearing with one another, and the first motion wheel of the train is driven by a worm or pinion on the armature spindle. The staffs of the various wheels carry either hands which travel over graduated circles on the front of the dial, or number discs or wheels, the figures on which appear in line opposite slots in the dial face. The integrating mechanism is invariably arranged so that its indications give the energy consumption direct in either Board of Trade or other convenient units without the use of a multiplier or constant.

A motor meter may be regarded as a motor-generator, the generator consisting of a magneto-dynamo with a short-circuited armature. The work the motor does is expended in driving the dynamo, in which the energy is ultimately absorbed in the shape of heat, in driving the counting train and gear, and in overcoming the remaining frictional resistances to motion. Meters of this class are very extensively used, and differ mainly in details of mechanical and electrical design, the relative arrangement of the various component parts, and the methods adopted to overcome the sources of error. In the descriptions which follow, the electrical features of motor meters will be mainly pointed out, and only those meters are included in this chapter which do not contain iron in the armature and field. In Chapter XIII. will be found a few of the more important mechanical details.

Thomson Watt-hour Meter.—The latest type of the Thomson watt-hour meter, manufactured by the British Thomson-Houston Company, Limited, Rugby, is illustrated in Fig. 28. It represents their standard house-service meter, form A, for two- and three-wire circuits. Two main current coils of rectangular shape are used, and are arranged parallel to one another, and with their planes at right angles to the base of the meter. They are securely held in position by means of clamps which fit in grooves in the meter base, and which are fixed by means of screws. By loosening these screws and disconnecting the two coils they can be readily removed to give access to the armature. The compound winding, which consists of a few turns of fine wire connected in series with the armature circuit, is divided into two sections, one being placed in each series coil. The compensating coils are adjustably mounted, and can be moved relatively to the main current coils, to alter the effect for the light-load adjustment. When the meter is calibrated at the works, the position of each compounding coil is adjusted until the supplemental torque is just sufficient to overcome the friction of the bearings, when the meter will register correctly on light loads.

Fig. 28.

If, however, a meter should afterwards be found to run slow on light loads owing to the bearings wearing rough, it is only necessary to readjust the position of each coil by moving it nearer to the armature, so as to increase the auxiliary torque to a point where the increased friction is balanced.

Symmetrically supported between the series coils is the armature, which is drum-wound and is composed of about 3000 turns of insulated fine copper wire. It is carried on a light steel spindle, which rests on a lower sapphire jewel-bearing, flexibly supported on a spring cushion in the jewel screw. The upper pivot of the meter spindle runs in a guide-bearing, which serves solely to keep it central.

The armature is wound in sections connected to an eight-part commutator, which is built up of silver segments and is mounted on the lower extremity of the spindle. Three phosphor-bronze wires are used for the brushes, and their ends are fitted with tiny silver sleeves, with which they bear on the commutator. They are kept in position by their own tension and are easily detachable. The commutator, brushes, and the jewel step-bearing can be quickly examined without having to disturb the main cover of the meter. They are protected by a separate dome-shaped cap, attached by a bayonet catch to the main cover, as shown in Fig. 29. This is an important consideration, as the commutator, brushes, and jewel form the vital parts of a meter, and constitute the chief sources of trouble inherent to meters of this class. They should therefore be quickly and easily accessible during the operation of the meter.

The brake system is arranged at the top of the instrument, and consists of two permanent magnets of tungsten steel, very carefully aged, and a brake disc of copper, which rotates between their poles.

The disc is mounted on the meter spindle which drives through a gun-metal worm the integrating train. The dial registers the energy consumed direct in B.O.T. units, and is carried on the same bracket which supports the high-resistance coil in series with the armature circuit.

FIG. 29.

The terminals are at the bottom of the instrument, and are protected by a separate ebonite cap, which also covers the fixing screws of the meter. The magnets are so mounted that their position relatively to the brake disc can be altered for the purpose of decreasing or increasing the speed of the meter at full load. With the general arrangement adopted, immunity is secured from any demagnetising action of the main coils, or other current-carrying parts, on the brake magnets. This might happen were these parts in close proximity to the brake system, and with excessive overloads or a short-circuit current the effect would become very pronounced.

In Fig. 30 is given a diagram of connections for a two- or three-wire meter up to 75 amperes, the dotted line showing the neutral or middle wire in a three-wire system.

The Thomson Meter.—The Thomson meters, manufactured by the

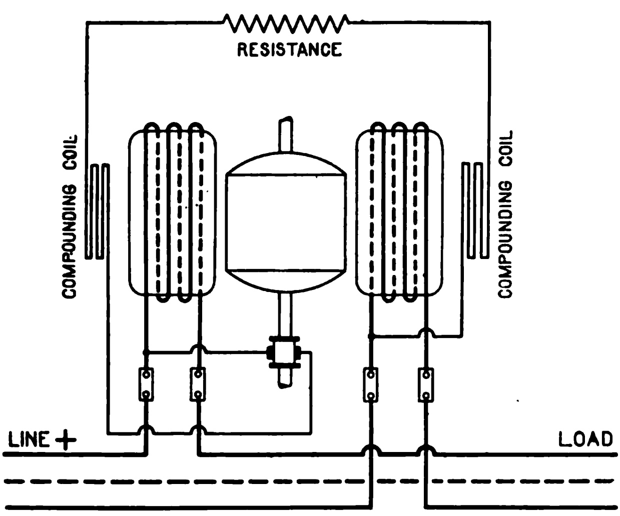

FIG. 30.

Compagnie pour la Fabrication des Compteurs, Paris, and by the Danubia Actiengesellschaft, Vienna, are almost identically the same as the one first

described. Slight modifications occur in connection with the brushes. These are composed of tiny silver lamellæ, bent round to form half-cylinders, and

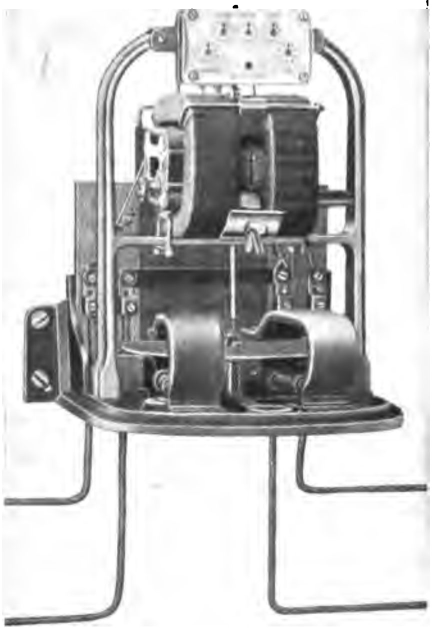

FIG. 31.

bear with their two edges on the commutator. The contact pressure is maintained by means of springs.

One of the main features of the Thomson meter of the General Electric Co., Schenectady, New York, U.S.A., consists in the use of a special adjustable compensating coil.

FIG. 32.

It is quite an easy matter to accurately compensate for any definite friction load. Friction, however, is a variable quantity, increasing somewhat with time and use; and unless the compensation be variable at will, inaccuracies occur.

The adjustable shunt field coil used by this company is very clearly shown in the illustration in Fig. 31 of their standard two-wire small capacity meter for currents from 3 to 50 amperes. It is shown more in detail in Fig. 32.

All their meters, up to and including 10,000 amperes, are now provided with this method of adjusting for light loads. In the two-wire meters, as illustrated, the coil is usually inserted within the left-hand main current coil, whereas in the three-wire sizes it is in the right-hand one.

The larger types, above 1200 amperes, have two of these coils, either or both of which should be used for making the compensation.

The adjustment can be very easily carried out without disturbing the meter when installed.

The winged nut which clamps the support of the compensating coil to the main current coils is first loosened, and the shunt coil is moved either towards or away from the armature until the required degree of compensation has been effected. Moving the coil towards the armature will increase the speed

FIG. 33.

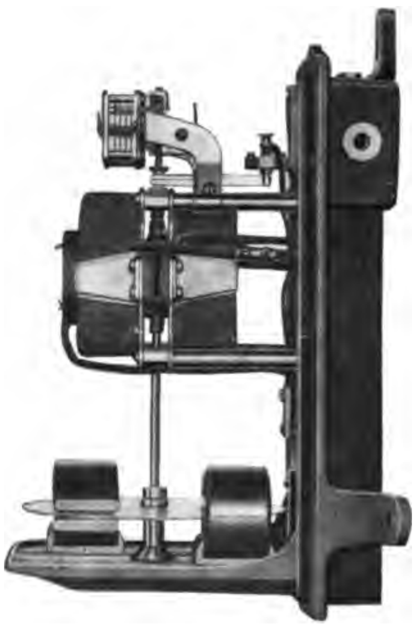

FIG. 34.

on light loads, and movement in the contrary direction will produce a diminution in speed.

The coil can also be centred, relatively to the armature, by moving it up or down, after releasing the knurled nut on the right of the coil frame by which it is fastened to its support.

The parts and general arrangement of the meter will be readily followed from the illustration, Fig. 31. The brake system in this case is carried on the bottom shelf of the meter, and the motor and integrating train are arranged well above the brake magnets.

The Duncan Watt-hour Meter, made by the Duncan Electric Manufacturing Company, La Fayette, Indiana, U.S.A., possesses many novel and interesting features. The general design of the meter will be gathered from the two illustrations shown, of which Fig. 33 is a front view and Fig. 34 is a side view of the meter. The two main current coils are supported with their

planes parallel to one another, and to the cast aluminium base at some distance from it. Both coils can be quickly and easily removed to allow for the inspection of the armature, commutator, and brushes. The brushes are made from hard-drawn phosphor-bronze having a thickness of ·008 of an inch. They are faced with silver on those portions which press against the commutator, which is composed of eight silver segments, gold-tipped. The brushes possess ample spring to ensure a good and reliable contact, and are mounted upon a moulded lava support, which does not, under the normal changes of temperature, cause the brushes to twist or get out of alignment, so that a constant pressure is maintained throughout all practical conditions of working. Another feature of the brush mounting is, that by removing only two screws the brushes with their lava support can be detached from the meter for inspection and cleaning without changing their original tension.

The main feature of the armature is the large number of turns of fine copper wire used, having a diameter of ·00314 inch. It is wound with 8000 turns, and in consequence, besides being efficient, produces a high torque, a very essential requisite to ensure accuracy and permanence of calibration.

A novel method is used for adjusting the friction compensation of the bearings and registering gear on low loads, and is accomplished by varying the turns comprising the compensating coil. The compounding coil, which is detachably secured within the front series coil, is wound with 1000 turns, which are subdivided into ten parts by bringing out as many terminals, soldered at regular intervals to the coil as a whole, and these terminals are connected to the contacts provided on a small multiple point switch situated on the front face of the back support. The compensating switch and coil are clearly shown in Fig. 33. When the meter leaves the testing department at the factory, the little switch arm is at about the centre of the contacts. If the meter be found to creep after being installed, due to vibration or increase of pressure above that at which it has been calibrated, the lever is moved to the right. This action cuts out turns from the compensating coil, and thereby reduces the intensity of the field produced by it. This, in turn, decreases the supplemental torque due to the coil, and creeping stops. If the meter, however, be found to run slow on light loads, such as one lamp, this shows that the friction of the bearings has increased. More turns of the compensating coil will therefore be required, and are thrown into circuit by moving the switch lever to the left. The increased number of turns of the coil augments the compensating field and increases the rotative power of the armature.

In this way the meter can be accurately and readily adjusted in position. The compensating coil has a small resistance, so that altering the number of the turns will not sensibly increase or decrease the total resistance of the armature circuit to which it is connected in series. The maximum alteration produced is found in practice not to exceed one-half of 1 per cent.

If required, the meter can be supplied with the compensating coil, comprising an independent pressure circuit of its own, quite distinct from the armature circuit. In this case it is made with wire having a high resistance.

The brake system is placed on the bottom shelf of the meter case at some considerable distance from the series field coils and all current-carrying parts; and the magnets, from their position, are quite unaffected by any current flowing.

These magnets are of tungsten steel, and are artificially aged in a very careful manner. The makers guarantee that their strength will not be impaired more than 1½ per cent. after the field coils of the meter have been

subjected to a short-circuit current through a fuse of capacity ten times that of the meter itself. Ample range for adjustment is made for these magnets on the bottom shelf, so that the correct speed can be obtained in testing.

The whole revolving element is made as light as possible by the use of a brake disc of aluminium and a hollow steel spindle. The disc is held on the spindle by means of a split hub, and the worm on the spindle drives the integrating train, which reads direct in kilowatt-hours.

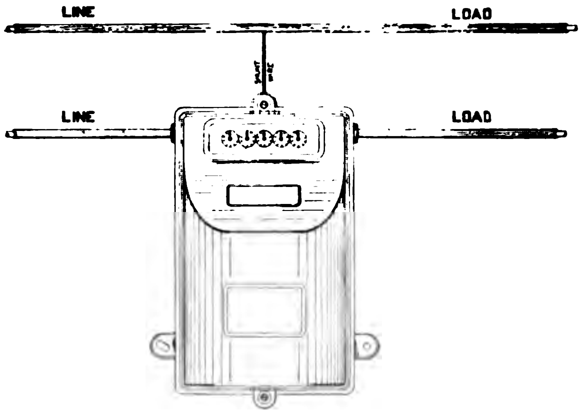

Fig. 35.

The terminals are secured to the sides of the pocket at the top of the meter base, and are insulated from the casting with pressed fibre.

To suit the different cases that arise in practice, the two-wire meters are supplied with either three or four terminals, and the three-wire meters with either four or five binding-posts. Fig. 35 is a diagram of connections of a two-wire meter fitted with three terminals, the pressure circuit being connected between the left-hand main terminal and the central shunt binding-post. In the two-wire meter with four terminals the armature connections are made within the meter and to the two left-hand terminals, to which the two supply mains are brought, the circuit mains of the installation being connected to the remaining two terminals. A diagram of connections for the three-wire meter with five terminals is also given in Fig. 36. In this type the armature circuit is connected between one of the outer supply mains and the neutral conductor, so that it is subjected to the pressure on one side only of the three-wire system. In their three-wire meter with the four binding-posts the armature circuit is also made within the meter, and is between the two outer conductors, so that the total pressure of the three-wire system is used in this

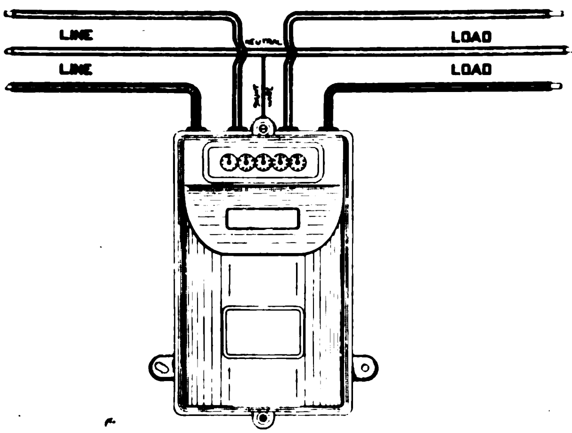

Fig. 36.

case. The arrangement of the four terminals is exactly the same as in the two-wire four binding-post type, no neutral connection being required.

By means of a 'visual' bearing, described and illustrated in Chapter XIII., the detachable spindle pivot and the jewel can be very readily and easily inspected without stopping the meter. The detachable pivot is retained in the lower end of the spindle by magnetism, the spindle being magnetised for this purpose.

Some further important improvements have been carried out by this company. One of these relates to an entirely new method of connecting the

FIG. 37.

armature with the commutator segments without having to resort to the soldering iron. In this manner new armatures may be placed in the meter with very great ease, avoiding the necessity of having to take the meter out of service. A new commutator can in a similar way be substituted on the spindle without unsoldering or resoldering any connections between it and the armature. A special switching mechanism permanently connected to the armature places it in electrical communication with the commutator. The

FIG. 38.

two are mounted together, and can be moved as a whole axially along the shaft, so that connection between the commutator segments and the armature is readily broken or made. This improved method of connection is illustrated in Figs. 37 and 38. Fig. 37 is a view of the armature and shaft with the brake disc removed, showing the commutator and armature connected for ordinary working conditions. In Fig. 38 the connection between the armature and commutator is shown broken, the armature hub having been lowered on the shaft for this purpose. The pivot has also been slightly withdrawn from the end of the shaft in this view. The ends of the armature coils are soldered to spring contact fingers, arranged in the form of a cone, and

mounted on an insulated conical support on the extension of the armature hub. The commutator segments are correspondingly extended, so that when electrical connection is established they press upon the armature terminals, which are flexible, and so give a good and reliable contact. The armature hub is securely locked on the shaft by means of two set screws, at right angles to one another. The shaft is made in sections, and the upper part carrying the commutator screws into the body of the shaft, from which it is removed by unscrewing it. When it is desired to renew a commutator, armature, or both, it is first necessary to loosen the armature on the spindle and lower it until contact is broken, as in Fig. 38. This is done in a few seconds by inserting a screwdriver between the armature coils and slightly releasing the two set screws. The commutator portion of the shaft can now be unscrewed and the armature removed if necessary.

On replacing these parts, the armature is first slipped on the shaft and lowered, the commutator is screwed into position, and the armature is raised until proper contact is again made, when the armature hub is once more locked.

The worm portion of the shaft is also made detachable, and is removed by simply unscrewing it at the knurled portion provided for this purpose. Further details of the shaft will be found in Chapter XIII.

FIG. 39.

The Vulcan Meter, made by the Compagnie Anonyme Continentale pour la Fabrication des Compteurs, Paris (Geipel & Lange, London), is very similar to the ordinary Thomson meter.

It differs from it in a few essential details. The armature consists of four coils, wound on ebonite formers, and the commutator is made of pure platinum segments, mounted on ebonite, with air insulation between them, and each brush is composed of four silver wires. The commutator and brushes are arranged at the top of the meter, and are protected by an independent commutator dome, easily detachable from the main cover of the meter (Fig. 39). They can, therefore, be very readily inspected, and cleaned if necessary.

A departure is made from the usual manner in connection with the Foucault brake system. Ordinarily a horizontal disc is employed, which rotates between one or more magnets, with the magnetic axis vertical.

In this meter a copper cylinder is used, which revolves between the poles of a series of vertically supported magnets, with their magnetic axes at right angles to the surface of the cylinder. In the illustration of this meter in Fig. 40 the arrangement is shown with ten magnets; in the latest type, however, four magnets only are being used. The adjustment of the brake is carried out in a manner different from that usually employed. Generally, the magnets are so mounted as to admit of sufficient displacement relatively

to the disc for alterations to be made in the speed of the meter. In this case the magnets, after being once fixed, cannot be altered. The brake cylinder is moved axially, so that it penetrates more or less into the polar gaps according as the speed is to be diminished or increased. The hub of the cylinder is screwed for this purpose, and the portion of the shaft which carries it has a screw thread on it, so that the cylinder can be quickly and easily rotated up or down along the shaft, affording a rapid method of obtaining a fine adjustment. The hub is locked with a small set screw, when the adjustment is complete.

Idle running is prevented by a small piece of soft iron on the brake cylinder. When the armature revolves under the action of a current in the main coils, the presence of the iron produces no effect. When current ceases, however, the armature rotates until the iron on the cylinder is between two magnets, in a position such that the resultant action of the magnets upon it counterbalances the driving torque due to the compound winding, and further rotation is arrested.

FIG. 40.

The compounding coil consists usually of one turn, and is situated in one of the main field coils.

The voltage across the armature brushes is comparatively high, amounting to twelve volts, but no sparking is experienced. The whole meter is insulated from the base by an ebonite bed, and the resistance in series with the shunt is wound on four bobbins and subdivided into eight coils.

The Eclipse Meter.—The Luxsche Industriewerke, Munich, Germany (G. Braulik, London), in their meter known in this country as the 'Eclipse' meter, use an open-coil armature consisting of three coils, with an angle of 120 degrees between them, as in the well-known Thomson-Houston arc light dynamo, in contrast to the closed-coil drum-wound armatures in most meters. With this construction the full shunt current flows through the coils, whereas in closed-coil armatures having parallel windings only half the shunt current flows through them.

Hence, all other conditions remaining the same, the turning moment will be much greater.

In addition, a three-part commutator only is necessary, and can, in consequence, be made of much smaller dimensions. Brush friction is considerably reduced hereby, a matter of importance at low loads, as the accuracy in this region is largely influenced by this source of frictional disturbance. Sparking at the brushes, when an armature coil is cut out during a revolution, is avoided by attaching a small short-circuited winding to each of the three armature coils. When a coil is cut out during the rotation of the armature, the field due to the coil disappears, and in disappearing induces an E.M.F. in the coil. This gives rise to a sudden extra rush of current, which is dissipated in the short-circuited winding and no sparking occurs.

An illustration of the meter is given in Fig. 41, and represents the standard 'Eclipse' type for both two- and three-wire circuits. For two-wire circuits up to twenty amperes the meter is slightly modified (Fig. 42); one

FIG. 41.

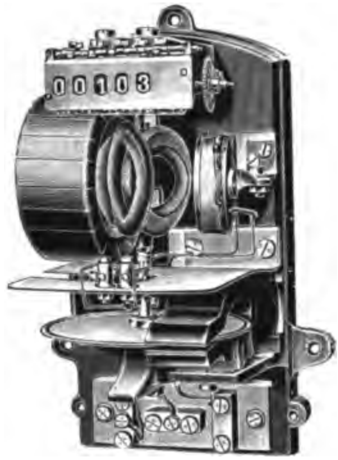

FIG. 42.

main current coil only is used, and the adjustable compensating winding is then separately mounted on one side of the armature, instead of being placed within a series coil as in the larger type.

The thin iron partition above the brake magnets serves not only to shield them from the influence of the main coils, but also to support the brush gear.

Fine silver-wire brushes are used, and are carried on small rods passing through slots in two terminal posts, which are mounted on and insulated from the shield. The rods are held in position by screws, and the brushes can be very easily adjusted and removed for inspection.

FIG. 43.

Mix & Genest Direct Current Energy Meter.—In the watt-hour motor meter, type A.G., Fig. 43, manufactured by Mix & Genest, Berlin (the International Electric Company, London), an oval-shaped armature is used, having two windings only. The two coils are wound in planes at right angles to one another, and their four ends are brought to a four-part commutator. The two windings are connected direct to the commutator segments, but are joined to each other through an auxiliary resistance mounted with the armature on the spindle. The usual high resistance in the pressure circuit of the meter is also used. Another feature of the connection between the

armature and the commutator is that the segments of the latter are extended through the hollow shaft and soldered to the ends of the coils, well within the armature. The object is to dispense with the small connecting wires, which would otherwise be necessary, and which are often a source of considerable trouble. The commutator is exceptionally small, being at its working part about a couple of millimetres in diameter. Brush friction is hereby much reduced. The segments are made of special silver alloy, and are held in, but carefully insulated from, small brass collars, which are mounted on the armature shaft. Between these collars is the part of the commutator on which the brushes bear. They are three in number, and are composed of silver ribbon, slightly rounded at their bearing ends. Two of the brushes press on the same side of the commutator, the one slightly in advance of the other. They are insulated from one another at the brush terminal, but are connected together through a small resistance, their junction being connected to a shunt terminal in series with the external high resistance and a small non-creeping device. The third brush bears on the opposite side of the commutator, and is connected direct to the other shunt terminal of the meter. By means of this arrangement of the pressure circuit, sparking at the brushes is completely avoided.

The armature is arranged symmetrically between two main current coils, which are held in massive gun-metal supports. Either coil can be easily removed to permit inspection of the armature and commutator.

The brake torque is provided by two permanent magnets, adjustably mounted, and a light aluminium disc, which rotates between their poles. The magnets are protected by a thin iron shield from any disturbing effect of currents in the main coils.

To prevent shunt-running, and supplement the driving torque on the armature at light loads, a tiny electro-magnet is used, the coil of which is energised by the pressure current. The keeper of the electro-magnet, consisting of a couple of thin rectangular iron plates, is mounted on the armature shaft, and rotates between the poles of the electro-magnet. The effect produced on the meter shaft by this device is regulated by means of a small screw, the poles of the electro-magnet being separated or drawn nearer together by its aid. In the view given of the meter the resistance of the pressure circuit has been removed, and the non-creeping device will be seen in front of the two main coils. Although the meter starts with one-half of 1 per cent. of full load, creeping does not occur with a 50 per cent. increase of the voltage above the normal. The meters are provided with two shunt terminals, so that the shunt circuit can be isolated for testing purposes, and a very complete subdivision of this circuit of the meter is employed.

Siemens-Schuckert Continuous Current Motor Meter.—The Siemens-Schuckert Werke, Berlin (Siemens Bros. & Co., Ltd., London), manufacture four types of continuous current motor meters on the electro-dynamometer principle, without iron in either the armature or the field. They differ principally in the number and position of the main current coils. Two of these, their GB and GK types, are included in this chapter, and illustrated in Figs. 44 and 45 respectively.

The GK meter is used only for the registration of small currents. The general arrangement of each form is clearly shown in the illustrations. In the small meter one main current coil is employed, whereas there are two in the larger type. The armature is ball-shaped and drum-wound, and is connected to a silver commutator, on which bear easily detachable silver-wire

brushes. An adjustable compensating coil is fitted to the meter, and is situated within a main current coil in all the forms except the GK type, in which it is arranged inclined to the armature and above it. A copper brake disc rotating between the poles of either one or more brake magnets forms the brake system, which is shielded against any demagnetising action of short-circuit currents by means of a sheet of iron.

The revolutions of the armature are conveyed in the usual manner to the clock train of an integrating mechanism.

To prevent idle running on the shunt alone, without any current in the series coils, under the influence of vibration, or shock, or increase of pressure, a small iron wire, designated a brake pin, is attached to the meter spindle above the brake disc. It is attracted by the steel magnets, and prevents

FIG. 44.

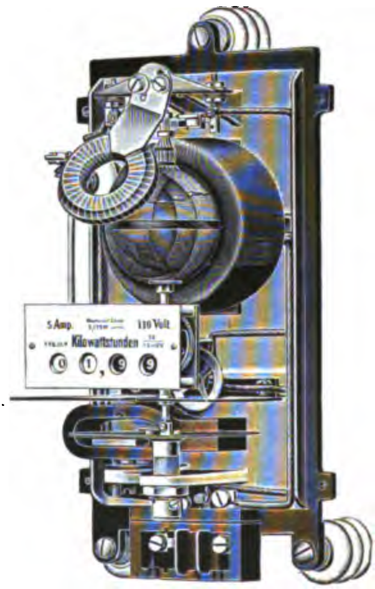

FIG. 45.

motion due to very small driving forces, but it is adjusted to allow the meter to readily start at 2 per cent. of full load.

Elimination of Friction.—In the preceding descriptions it will be noted that the usual method adopted to neutralise the effect of friction is to correct for it by means of a starting coil traversed by the shunt current, and so arranged that its magnetic field assists that due to the main current coils. In this manner a more or less effective compensation can be applied. The difficulty lies in the fact that friction at low loads is not constant, but is a variable quantity. Another disadvantage is the tendency of the meter to run on the shunt alone. The magnetic field due to the compensating coil is always present, as the shunt circuit is always energised, and a constant turning moment is being continually exerted on the armature, although there may be no current in the main coils. A small increase in the voltage, slight vibration, or a jar will often be quite sufficient to start a meter. In consequence, a non-

creeping device is introduced, most commonly in the form of a light piece of iron wire on the brake disc, which prevents the meter from starting below 1 per cent. to 2 per cent. of the maximum load.

The problem of obtaining a straight line law can be almost solved, without the use of a correcting coil, by eliminating as far as possible the sources of friction.

A large driving torque should be used permitting a heavy magnetic drag, so that the work done by the meter in the generation of Foucault currents should be large in comparison with the work the meter has to do in overcoming the friction of the axle-bearings, the friction of the brushes on the commutator, and, lastly, the friction of the counting train and gear connecting it with the motor axle. In other words, the ratio of the driving torque to the frictional retarding torque should be as high as possible, and the driving torque per unit weight of the revolving element should also be large. The driving torque, *per se*, affords no criterion of the behaviour of a meter under working conditions, and is no guarantee of the retention of its original accuracy. The weight of the revolving element, and, if possible, the frictional retarding torque, should also be stated, together with the driving torque and shunt loss at the particular voltage. All these figures have a definite relationship to one another, and in making a comparison of meters it is essential to know them all.

The Evershed Frictionless Motor Meter.—Mr Evershed, in his frictionless motor meter, manufactured by Evershed & Vignoles, Ltd., London, uses the method of removing the various causes of friction, and has succeeded in reducing the latter quantity to an even smaller value than 3 dyne-centimetres. He attains this end in the use of several ingenious devices.

A magnetic suspension of the entire revolving element is used, and a top bearing is entirely dispensed with, the axle being held in position magnetically, *i.e.* magnetically pivoted. The brush friction is reduced by the employment of a novel form of commutator having elastic segments, and by the use of two light and freely pivoted wheels as brushes.

The friction of the counting train and gear is entirely removed from the meter axle. The train is driven by an electro-magnetic device, the speed of working of which is controlled by the speed of the motor without any mechanical connection between them.

The working parts of Mr Evershed's meter are illustrated in Fig. 46. A mild steel axle *a* supports the armature A, the brake disc F, and the coils D_1 D_2 which actuate the counting train.

The jewel cup in which the axle rests is shown at J; its upper end has no mechanical support, but is maintained in position by the magnetic attraction of an iron rod R, which is magnetised by the brake magnets M M through an iron yoke Y and forms the supporting pole. The distance between R and the end of the axle is adjusted by screwing R in the yoke Y until the vertical force nearly suffices to lift the whole weight of the armature, brake, and other parts attached to the axle. K is the commutator placed beneath the armature; *b b* are the wheel brushes. The latter are pivoted in frames fixed on an ebonite base E. The commutator segments are fine iridio-platinum wires, supported at one end in an ivory collet, and entirely free at the other end, where they impinge and roll on the brush wheels. The pressure circuit is led to the brush wheels through their frames, and the step-bearing of each wheel consists of an iridio-platinum pivot resting on a flat plate of the same metal. The armature is arranged astatically, and is divided into two equal

portions, placed one above the other on the axle. A drum-winding is used for the armature, a break being made, in the ordinary course of winding, in each parallel, in order to insert the two little coils D_1 and D_2.

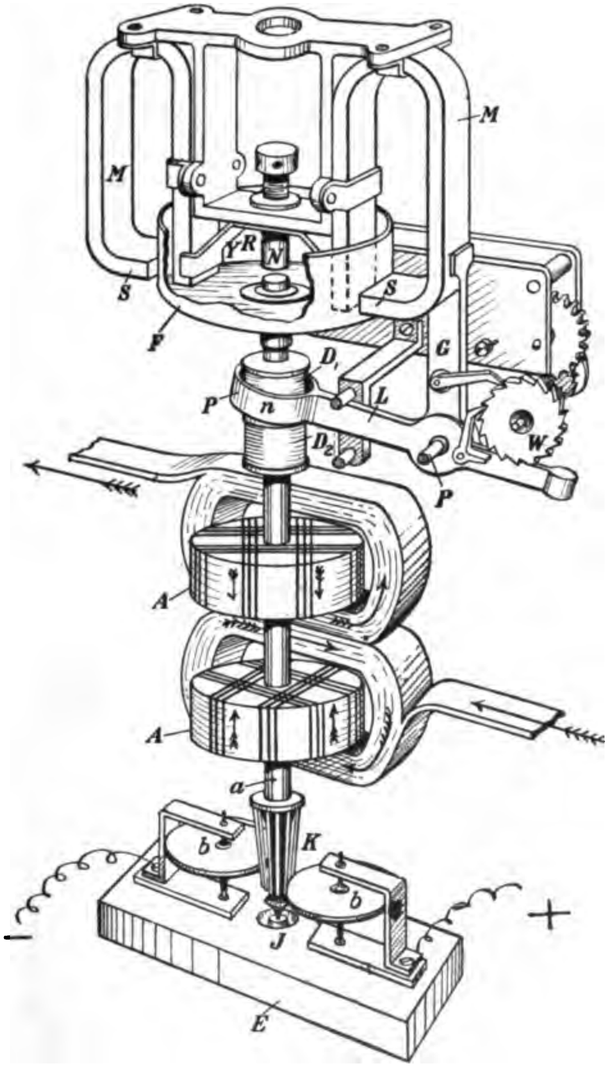

FIG. 48.

D_1 is in series with one of the two parallels of the drum-winding and D_2 in series with the other. They are consequently each traversed by one-half of the whole armature current; and as they form electrically a part of the armature circuit, the current in them is reversed twice in each revolution of the axle. The currents in D_1 and D_2 are such that they reverse at the same

instant and flow in the same direction. Surrounding the train coils D_1 and D_2 but not touching them is a ring of soft iron P, forming part of an iron lever L, mounted on a horizontal axle p. L is magnetised by induction from one of the brake magnets, the iron bar G completing the magnetic circuit between S and n. P rocks up and down as the currents in the main coils periodically reverse, causing L to make a complete oscillation on its axis in every revolution of the armature. The motion of the lever is limited by stops, and is communicated by means of a pawl to a ratchet wheel W, which is attached to the first axle of the counting train. It will be seen from the position occupied by the brake magnets relatively to the main current coils that it is impossible for any excess current to demagnetise them, as their field is at right angles to that of the main coils.

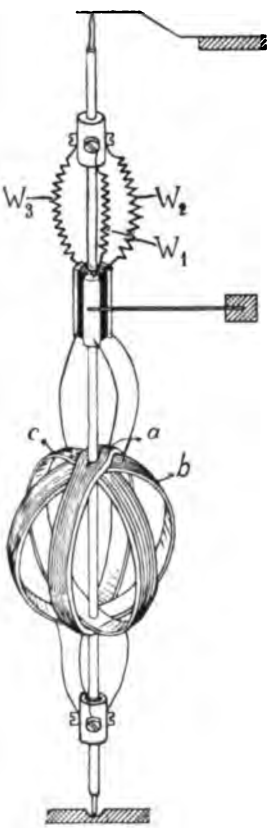

FIG. 47.

Hartmann & Braun Motor Meter.—Messrs Hartmann & Braun, Frankfort (the Union Electric Company, Ltd., London), manufacture a very simple meter, in which they obtain a high ratio between the driving torque and friction by minimising the frictional resistances inherent to meters of this class.

A single brush, with a three-part commutator of small diameter and a light revolving element weighing about 100 grammes, form the characteristic features by which they attain this end.

Experiments prove that brush friction is the most fruitful source of trouble in commutator motor meters, and is a maximum as the brush passes from one commutator segment to the next.

This passage takes place three times per revolution per brush on a three-part commutator, so that in this case the frictional disturbance is considerably less than in an ordinary Thomson meter with two brushes and eight commutator segments.

With the arrangement adopted, the total friction is so considerably reduced that no compensating coil is required, exerting a continuous turning moment on the armature, both when current is and is not flowing in the main field coils.

The special connections adopted for the armature circuit permitting the use of a single brush are shown diagrammatically in Fig. 47.

The armature is composed of three coils, a, b, c, which are arranged at an angle of 120 degrees with one another. In conjunction with the armature coils, three resistances w_1, w_2, and w_3 are used, each coil being in series with a commutator segment and a resistance.

The free ends of the coils, as well as those of the resistances, are joined together, and the common junction of the armature windings is insulated from the spindle. The current enters the armature circuit at the point of the common connection of the resistances with the armature spindle by means of a light spring which presses on the latter. It is conducted away by the one brush on the commutator.

The armature coils are all similarly wound from the commutator, and current flows in them so that two are always polarised in the same sense, whereas the third, in which the current is double that in the other two, is of the opposite polarity. The total current in the armature remains practically constant during a revolution, and only increases by a very small percentage at the moment when the brush is making simultaneous contact with two segments.

The meter itself is illustrated in Fig. 48.

It consists of the armature and resistances, a main current coil, the usual magnetic brake, situated at the top of the instrument, and a counting mechanism with springing figures. The resistance coils connected to the armature windings weigh only about 5 per cent. of the total weight of the moving system, and they are therefore mounted with the armature on the spindle. The resistances used in the pressure circuit to keep the current in the armature low are wound in sections on bobbins fixed to the meter base on either side of the counting mechanism. In the two-wire meter only one main current coil is used; the whole instrument is exceedingly compact, and its parts are readily accessible. The top spring connection is protected by a small shield, and the brush and the commutator are clearly shown in the illustration. No compensating coil is employed, but two small electro-magnets produce a supplemental torque for equalising the whole driving torque. As already indicated, with the special armature connections adopted, one armature winding always carries a current of double the strength of that flowing in the other two coils, and each electro-magnet is so arranged that the torque it exerts acts in a positive sense on this coil, and only at the moment when the reversal takes place, *i.e.* when the brush is leaving the segment joined to this coil. The sphere of action of each electro-magnet is thus limited to one coil, so that shunt running is completely prevented.

FIG. 48.

The two electro-magnets—as will be seen in the illustration of the meter—are in front of and on either side of the armature, and are supported on springs attached to the uprights on each side of the main field coil.

They are further so arranged that they cause the meter to run comparatively faster at low loads than at full loads. With this improvement their meter, when new, will run somewhat too fast, so that in case the friction should increase during long-continued use, it will show a better and not a worse agreement between the constants at the low and high loads.

CHAPTER V.

CONTINUOUS CURRENT ENERGY METERS OF DIFFERENT TYPES.

Aron Clock Meter — Electrical Company's Oscillating Meters — Acme Meter — Deutsch-Russische Meter—Peloux Meter—Brush Sangamo Mercury Meter—Hookham Mercury Meter.

In the present chapter are included descriptions of some direct current energy meters, which, although based on the well-known electro-magnetic principle, differ in many essential details from the energy motor meters included in Chapter IV. Many of these meters are typical of distinct classes, and in some cases are the only representatives in commercial use.

The Aron Clock Meter.—The most successful clock meter in use at the present day is the well-known Aron watt-hour meter, invented by Dr Aron, of Berlin. Only the latest form, embodying the most recent improvements, is here described. The principle of the Aron meter is the same as that employed in all continuous current energy meters, with the difference that the electro-magnetic interaction between the currents in the stationary and movable coils is not used to produce motion, but to influence an already existing one—in this case, the swing of a pendulum.

The very simple mathematics illustrating the law of the meter is given on page 23 in the chapter on the theory of continuous current meters, from which it will be seen that the meter depends on the difference in the rates of oscillation of two pendulums. The meter readings are not in any way dependent on the actual speed of either pendulum, but only on the differences in speed produced by the passage of a current in the circuit to which the meter is connected. In the earlier forms one pendulum only was accelerated by the current, while the other simply oscillated at the normal rate, acted upon by the force of gravity alone.

A greater sensitiveness and range are, however, obtained by arranging both pendulums so that each is influenced by the current, as in the present type, the one being accelerated and the other retarded. Distinct from the older patterns, the axes of the different coils are all vertical.

A general view of the two-wire house-meter, with the cover removed, is given in Fig. 49. Fig. 50 illustrates the arrangement of the pendulum P with pallet p, escapement wheel E, and potential coil C.

Each pendulum carries a potential coil, energised by the supply voltage, and swings above a stationary main current coil. The two pendulum coils are connected together in series and with resistances, to reduce the voltage across their terminals and keep the shunt current low. They are similarly wound, and are each traversed by the shunt current in the same direction.

The two main current coils are also in series with one another, but are wound in opposite senses, so that the main current flows in one in a clockwise and in the other in a counter-clockwise direction. As each pendulum

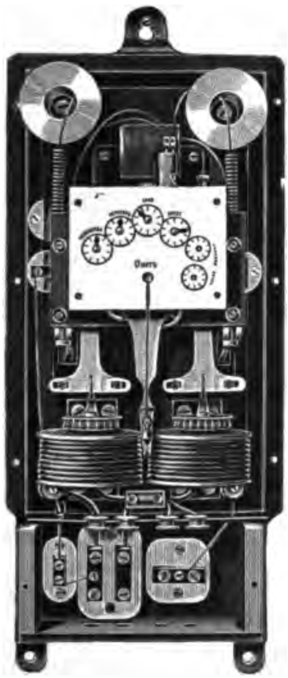

FIG. 49.

FIG. 50.

coil presents the same polarity to the series coil above which it oscillates, and the two series coils are oppositely polarised as regards one another, the result is a retardation of the one pendulum and an acceleration of the other. The difference in speed thus produced is proportional to the power in watts, and is continuously integrated by means of a differential gear and counting mechanism, in every way similar to the method employed in the earlier meters. The differential gear is illustrated in Fig. 51, and the parts are shown in Fig. 52. It consists of two side wheels W_1 W_2 running loose on their shafts, and driven in opposite directions by the two clocks at speeds respectively proportional to the rates of swing of the two pendulums. Between the

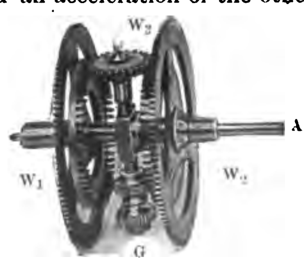

FIG. 51.

two wheels, and gearing with them, is mounted the planet wheel W_3 at right angles to their planes, and carried on a spindle rigidly attached to the main horizontal axle A. So long as no difference in speed exists between the two wheels W_1 and W_2 the planet wheel W_3 will merely revolve on its own axis, but as soon as one wheel goes faster than the other it will turn round and

carry with it the counterpoises G and the main axle A. The motion of the main axle is communicated to the train of wheels moving the pointers on the dials, which sum up the differences in speed and indicate in the usual manner the amount of energy consumed in B.O.T. units. The clocks are made self-

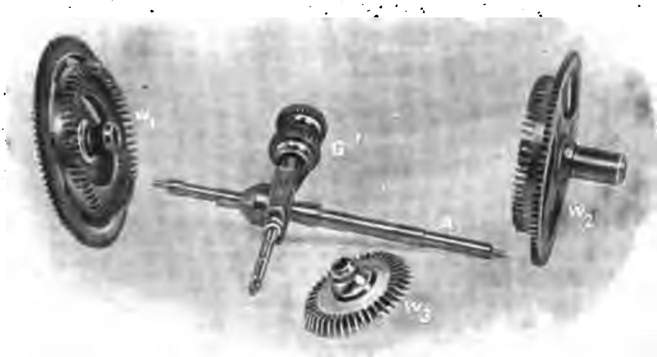

FIG. 52.

winding by means of an electrical winding gear, removing the disadvantage, inherent to the earlier meters, of the necessity to periodically wind up the clocks. Without the electrical winding arrangement, it was essential to wind up the clocks about once a month, as otherwise the clocks would stop, and the record with them.

FIG. 53.

A front view of the gear is shown in Fig. 53, and the three Figs. 54, 55, and 56 are diagrammatic representations to illustrate its working.

The power spring S (clearly seen in Fig. 54) controls the two clocks, and is wound up every thirty seconds by means of an electro-magnet M. The armature of the electro-magnet consists of a Z-shaped piece of soft iron N, pivoted between the poles. Attached to the armature at R is the spring S, the other end of which is secured to the magnet frame at F. The winding gear in its normal position before the spring is wound up is shown in Fig. 54. The electrical circuit is indicated by the dotted line A, and is opened and closed at the contact pin X by means of a special switch K, which is pivoted at D. When the circuit is closed and current passes, the coil of the electro-magnet becomes energised. The armature N is then attracted and is rotated clockwise through about a quarter of a revolution, carrying with it the power

spring S, which is thus wound up. This condition with the spring fully wound is shown in fig. 55.

Simultaneously the pin X, which is fixed to the armature, is turned round and opens the switch, the insulated right-hand arm of which now rests on the pin instead of the silver contact plate Cp, to which the other end of the circuit is joined at D.

As the spring uncoils it brings back the armature, and with it the pin X.

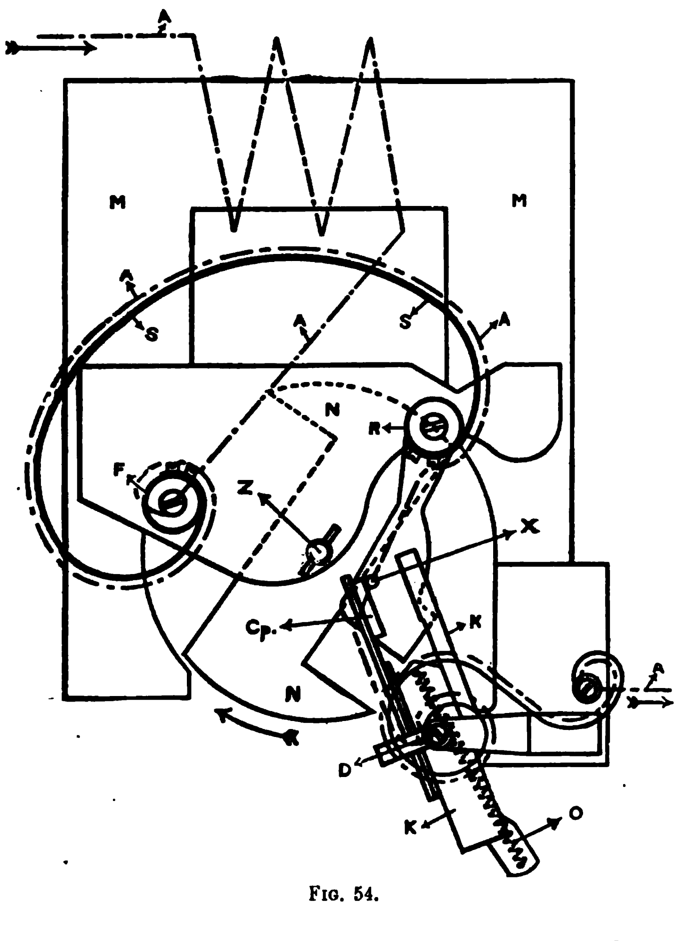

Fig. 54.

When it reaches the normal position, contact between X and Cp is again established and the circuit closed.

A small amount of surplus power is left in the spring, so that a rubbing contact is always obtained between the plate Cp and the pin X. In addition, a quick make and break action is given to the switch by the spring O. This spring is fixed to the switch above its point of rotation, and pulls it sharply on or off, according to the position of the switch relatively to its pivot D. The whole switch gear is mounted on rubber to render the operations of open-

ing and closing the circuits as noiseless as possible. The contact plate Cp is carried by a flat spring attached to its arm.

The driving spindle Z is actuated by the power spring S through a ratchet wheel and two pawls, shown in Fig. 56. The ratchet wheel is keyed to the driving shaft, and, while the spring is being wound up, is held in position by

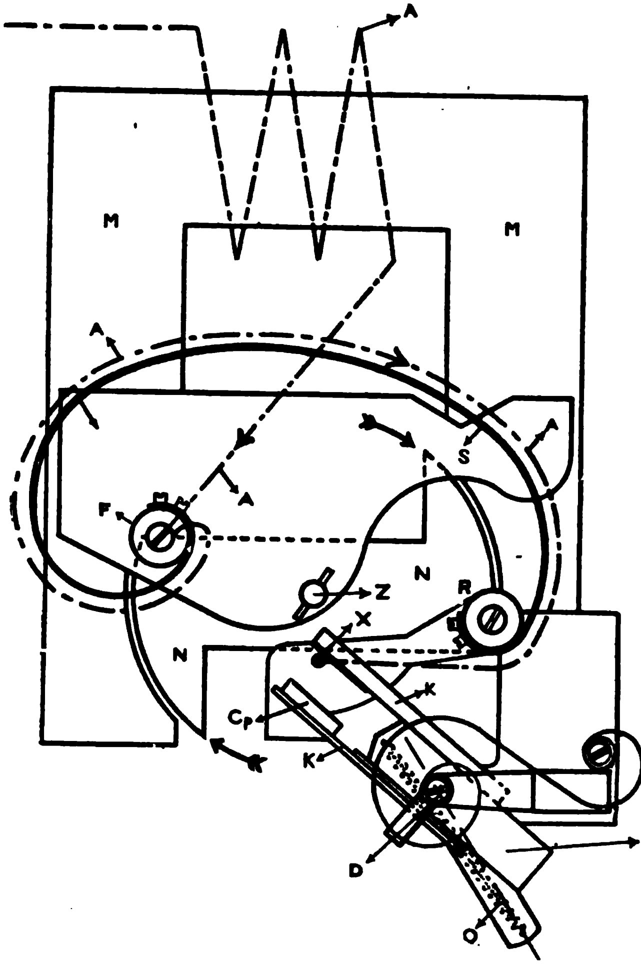

FIG. 55.

the upper pawl P, which is fixed to the magnet frame. As the spring unwinds, the ratchet wheel is driven round by the lower pawl P_1 on the armature. In order to enable the two clocks, going at different rates, to be driven by one mainspring, a second differential gear, precisely the same as that already described, is introduced.

It has been explained how the differences in speed between the two pendulums are transmitted to the counting train; and consequently any

want of synchronism between the pendulums, when no current is flowing in the main coils, would be registered on the meter dials either one way or the other.

This effect is neutralised by introducing a reversing mechanism, Fig. 57, which at regular intervals of ten minutes causes an extra wheel to be placed in or out of gear between the differential wheel and the counting train, reversing the direction of rotation of the latter.

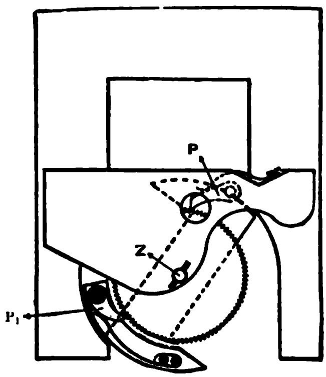

FIG. 56.

Referring to Fig. 57, D_1 is the driving wheel on the differential gear which actuates through the intermediate set of wheels the first motion wheel D_2 of the integrating dials.

Acting alone, this reversing mechanism would also destroy the differences of speed produced by the passage of a current, so that a commutator is employed in conjunction with it. This commutator, simultaneously with the action of the reversing mechanism, reverses the current in the pendulum coils, causing the retarded pendulum to be accelerated, and the accelerated one to be retarded. The commutator C, illustrated in Fig. 58, is mounted on an axle which carries on its front end the cam C_1. By means of the pin attached to this cam the wheel work of the reversing gear is controlled. Both mechanisms are driven by the main power spring, but a

FIG. 57.

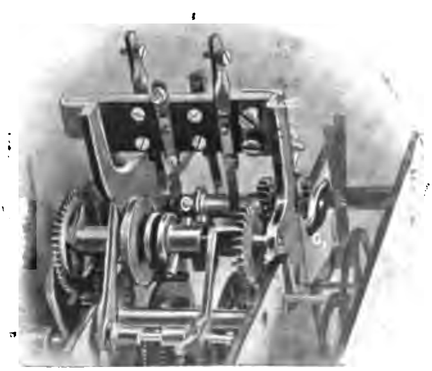

FIG. 58.

small intermediate spring produces the quick action necessary to work the commutator. It is wound up and suddenly released every ten minutes, rotating the commutator through half a revolution and operating the reversing lever.

The meter is unaffected by external magnetic fields. This result is due to the two potential coils on the pendulum bobs being similarly wound, and

being each traversed by the shunt current in the same direction. Each pendulum is therefore influenced by the stray field external to the meter in exactly the same manner; each is either accelerated or retarded. This will, however, not in any way influence the meter indications, as they depend solely on the difference in speed of the two pendulums, and not on the actual rate of oscillation of either.

From the principle of the meter it follows that any current in the main coils, however small, will gradually accumulate a correct record on the dials.

The energy expended in the shunt circuits amounts to a little over three watts for a 200 volt meter.

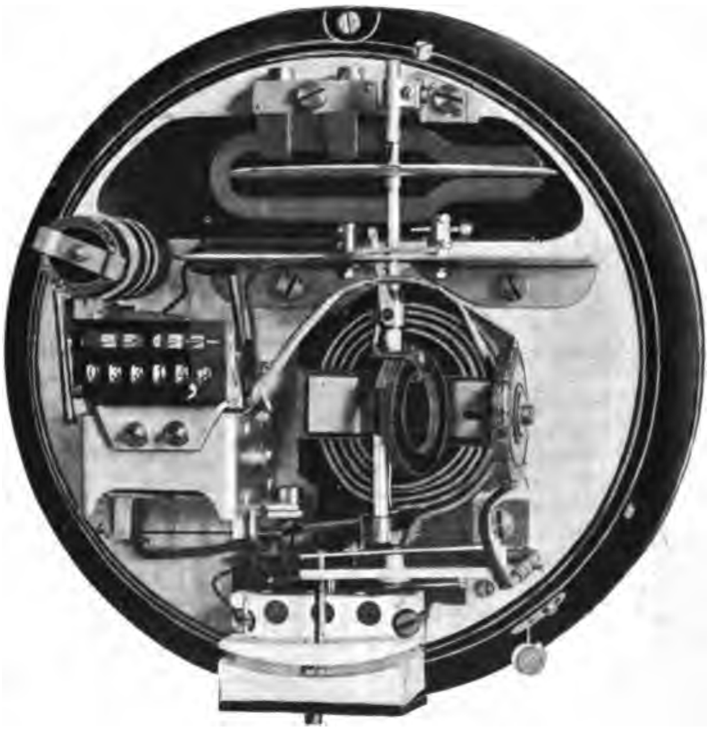

FIG. 59.

The Aron meter is equally accurate on direct and alternating currents For alternating currents, however, the winding gear, being highly inductive, must be wound to suit the periodicity of the circuit on which it is to be used.

In the three-wire meter each main current coil is inserted in one of the outer mains, and the pressure coils are connected in series across the whole three-wire system, the junction of the two volt coils being connected to the neutral wire. The Aron three-wire meter, therefore, measures the true energy consumption in the whole system when connected in this manner, however unbalanced the two sides may be, and whatever the nature of the supply current, in contrast to the ordinary three-wire energy motor meter, which only gives the true amount under certain conditions.

The Electrical Company's Oscillating Direct Current Meter.—The continuous current watt-hour meter of the Electrical Company, Limited, London, has many characteristics distinguishing it from energy meters designed for continuous current work. In common with all these meters the same principle is used, but, by adopting a special device, an oscillatory motion is produced instead of one of rotation.

The armature coil, which is in the pressure circuit, oscillates between two fixed points in the magnetic field of the main current coil. No iron is used in

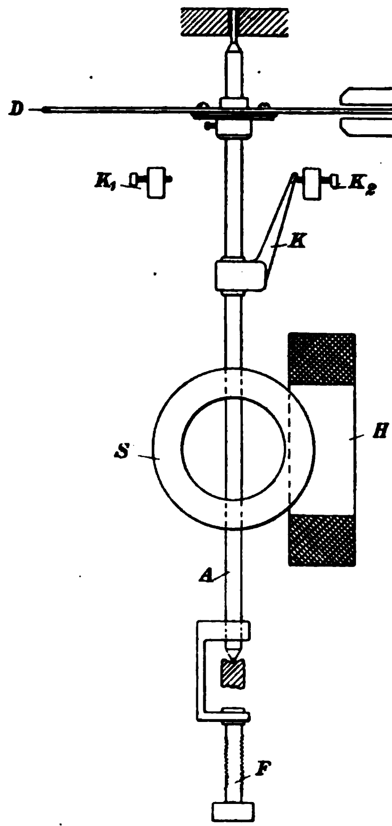

Fig. 60.

either the field or armature. Current is conducted to and from the oscillating coil by means of two fine helical silver threads, and brushes and a commutator are dispensed with, entirely removing the frictional disturbances incident to their use. The meter is made in two parts, electrically but not mechanically connected—the meter proper, and a relay actuating the counting train.

Fig. 59 is an illustration of the meter, type K.G., and in fig. 60 is given a diagrammatic sketch of the swinging system.

H is the stationary main current coil, in front of which the armature S is mounted on the vertical axle A. The axle rests on a bottom ball-bearing,

flexibly supported, and has attached to it the contact arm K and the brake disc D. This disc, together with the permanent magnet M, constitutes the usual magnetic brake. The magnet is screened from any demagnetising action of the main current coil by a thin iron sheet, which further serves to carry the contact stops K_1 and K_2. These stops limit the extent of the oscillation, and, in conjunction with the contact arm and the relay, reverse the direction of the shunt current in the armature coil in a manner to be described later.

At F are shown the two helical silver conducting threads, which are of such a length that their torsion does not affect the swings.

The relay is diagrammatically represented in Fig. 61. It is composed of two electro-magnets E_1 and E_2, the common armature of which is fixed to the pivoted arm R. This arm establishes electrical contact alternately with each of two contact stops C_1 and C_2 according to which electro-magnet is operating. The rocking motion of R is communicated to the counting train through a pawl *s* and a ratchet wheel *r*.

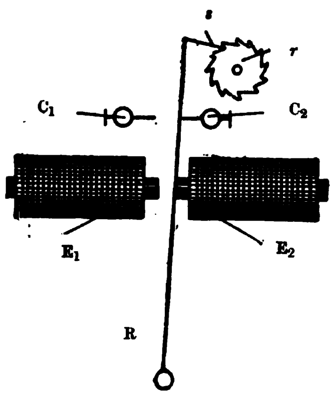

FIG. 61.

The counting mechanism is of this company's well-known cyclometer type, and its friction is completely removed from the oscillating meter axle in this manner. Further, the work expended in actuating the train is accomplished by the shunt current.

No starting coil is used, and consequently the meter is free from running on the shunt alone.

For very low loads, below one-tenth full load, the field due to the resistance coil on the right of the armature in the small type, Fig. 59, is used as a fine adjustment for friction in the calibration of the meter. The field of this coil is, however, so weak that with double the pressure it does not produce creeping.

The action of the meter can best be followed from the diagram of the electrical connections given in Fig. 62. S is the oscillating armature coil, H is the main coil, r_1 and r_2 are the resistances used in the pressure circuit, and K_1, K_2, and K are the contact stops and contact arm of the meter proper. The relay circuit is shown in the same way, above the connections of the meter; E_1 and E_2 are the two electro-magnets, and R is the rocking arm carrying the common armature, C_1 and C_2 being the two relay contact stops.

In the position shown, the coil S is just about to complete its forward swing from left to right.

The current in the shunt circuit is flowing from the + shunt terminal round E_2 to the contact C_2. From this point it is passing down the armature coil S in shunt with the resistance r_1, and leaves by the − terminal after traversing the resistance r_2 in series with the second electro-magnet E_1. This condition obtains until the arm K impinges on K_2 at the end of the swing. The electro-magnet E_2 is immediately short-circuited on itself, and the path of the current is through K_2 and K into the armature coil S in series with both r_2 and E_1. No current is in E_2, and the contact at C_2 is broken by the arm R being pulled over by the attraction of E_1 on its armature, when contact is made at C_1.

The arm K now leaves the stop K_2 due to the impact; it does not strike the stop and leave it instantaneously. The actual contact is made by a platinum strip flexibly carried on the arm itself. The result is that contact is maintained just long enough to allow the relays to operate before the armature contact is opened.

It will be seen that in this manner no part of the pressure circuit is broken under current, and that no sparking, with the consequent wear at the contacts, can occur. The moment K leaves K_2, the current is reversed in the coil S, which now executes a backward swing from right to left. At this stage the current takes the path from the + shunt terminal to E_2, in series with r_1. It then flows up the armature coil in shunt with the resistance r_2 and passes from the contact C_1 round the electro-magnet E_1 to the – terminal of the meter. As soon as K touches K_1 the same cycle of operations is repeated, but reversed as regards direction, and the armature starts to swing again from left to right.

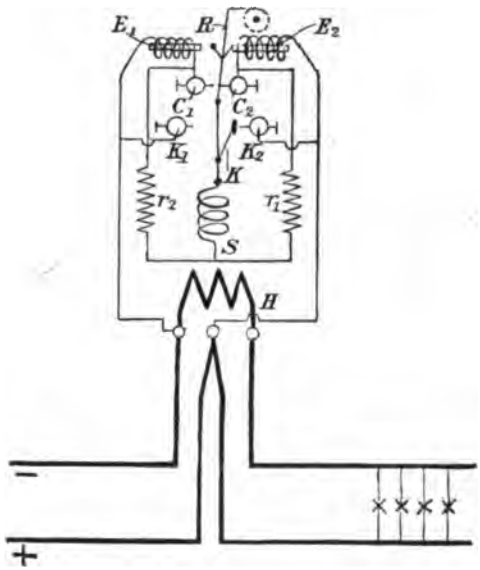

Fig. 62.

It, of course, continues to oscillate backwards and forwards so long as a current is flowing in the main coil. During each complete oscillation the ratchet wheel on the first motion shaft of the counting train is advanced through one tooth. A complete oscillation, *i.e.* the whole motion of the swinging coil in passing a given point twice in the same direction, corresponds to a complete revolution in a motor meter with continuous rotation. The number of complete oscillations executed in a given time will be, in the same manner, proportional to the energy delivered in that time.

The action of the meter is quite continuous, and is not intermittent as in meters with periodic addition, which form a class distinct in themselves. These intermittently registering meters are, however, not used at the present day.

The meter is suitable for two- and three-wire continuous current circuits up to 100 amperes. Above this current the Electrical Company use their large oscillating meter, which is exactly the same in principle as the one just described. It differs from it in a few particulars. Two main current coils are used, and the armature, which is symmetrically supported between them, consists of two half coils oppositely wound, each of which is furnished with its own contact arm. Three helical silver threads are used in this type to conduct the current to and from the swinging coil. The relay and the counting mechanism are actuated in exactly the same way as in the smaller meter, but the windings of the relay magnets are in series with the two halves of the armature coil and the two resistances of the shunt circuit.

Two brake magnets are usually used. The general arrangement of a two-wire meter, type G, suitable for 800 amperes, is depicted in Fig. 63. The armature coil oscillates, as before, between two contact stops. During a swing from one extreme position to the other, only one winding of the armature is active, the other remains short-circuited on itself until this swing has been completed, when it becomes the active half, and the other, previously in circuit, is short-circuited on itself and remains inoperative until the armature again starts from its initial position. Figs. 64, 65, 66, and 67 show how this oscillatory motion is obtained, and represent diagrammatically the electrical circuits of the meter and relay.

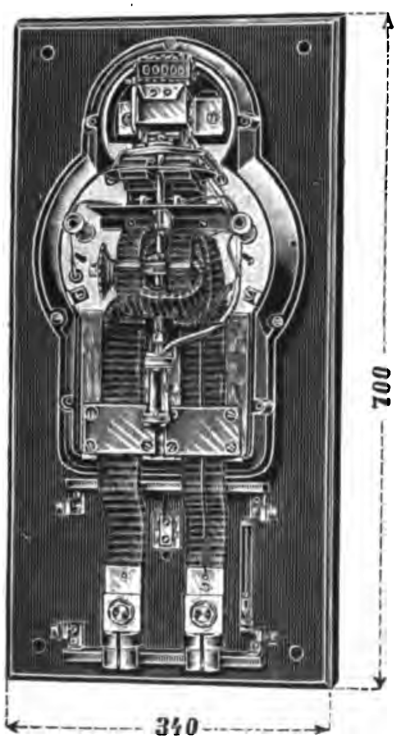

FIG. 63.

Fig. 64 gives the extreme position on the left, with the coil just about to swing from left to right. In all the figures the shaded portions indicate those circuits which are short-circuited on themselves and do not carry any current. In this position the current flows through the right-hand electro-magnet in series with the left-hand winding of the armature coil and the two resistances.

Fig. 65 shows the coil in the middle of its swing, the two electro-magnets being now in series with the same winding as in Fig. 64 and the two resistances. Fig. 66 is the extreme right-hand position. It will now be seen that the right-hand coil, which has remained short-circuited throughout this swing, is now operative, and that the right-hand electro-magnet winding is closed on itself.

The current now passes through the right-hand coil in series with the resistances and the left-hand relay. It is, moreover, reversed in the armature, so that the armature coil will be repelled from this position and will swing back. Fig 67 corresponds to Fig. 65, but the current conditions are interchanged as regards the windings.

No starting coils are used in this type, and the meters do not register on open circuit.

As in the small type, the resistance coil on the left of the armature and field system (Fig. 63) supplements the driving torque for loads below one-tenth load, and this coil is adjustably mounted, so that its effect can be regulated in calibrating the meter.

They readily start with 1 per cent. of the maximum current, and the registration is made on this company's usual cyclometer counter.

The meter is unaffected by external magnetic fields, as the two halves of the armature coil form an astatic combination.

The 'Acme' Direct Current Watt-hour Meter exhibits some novel

features of construction and arrangement. Its armature consists of an astatically arranged iron core, magnetised by a single stationary shunt coil and caused to rotate by two stationary main current coils. The relative position

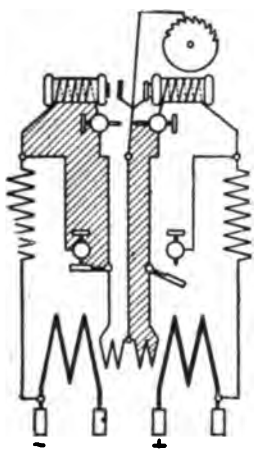

FIG. 64.

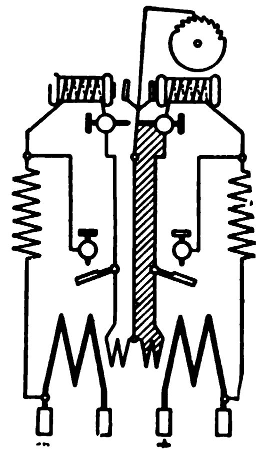

FIG. 65.

of the shunt and main coils is well shown in the view given of the meter in Fig. 68.

The utilisation of the iron armature enables a large torque to be obtained with a light revolving element. The hysteresis errors due to the use of iron

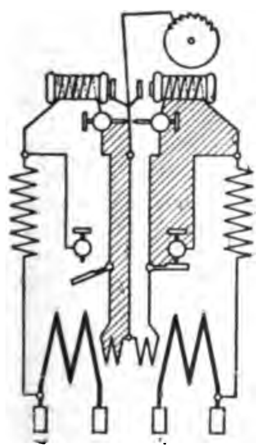

FIG. 66.

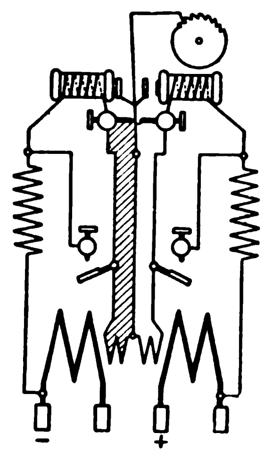

FIG. 67.

are small and do not affect the accuracy of the meter. The iron core is so constructed that the upper pole-piece, readily visible in the illustration, revolves inside, while the lower one revolves outside the field coils. Both pole-pieces are situated on the same side of the armature spindle and are in close proximity to one another. This renders the instrument almost

completely independent of external magnetic influences. The work done by the meter is absorbed, in the customary manner, by eddy currents generated in an aluminium disc, which is supported at the upper extremity of the armature axle, and which rotates between the poles of a permanent magnet. The polarity of the shunt coil is reversed twice in each revolution of the armature by means of a special commutating device. This latter is composed of a laminated commutator mounted on its own shaft, supported on two special bearings. The commutator has no mechanical connection with the armature spindle. Both the commutator brushes are electrically connected to the stationary shunt winding, and the current is led to the commutator segments by two small contact blades which bear on them. The commutating mechanism is situated on the right of the meter axle, and can be easily seen in the illustration.

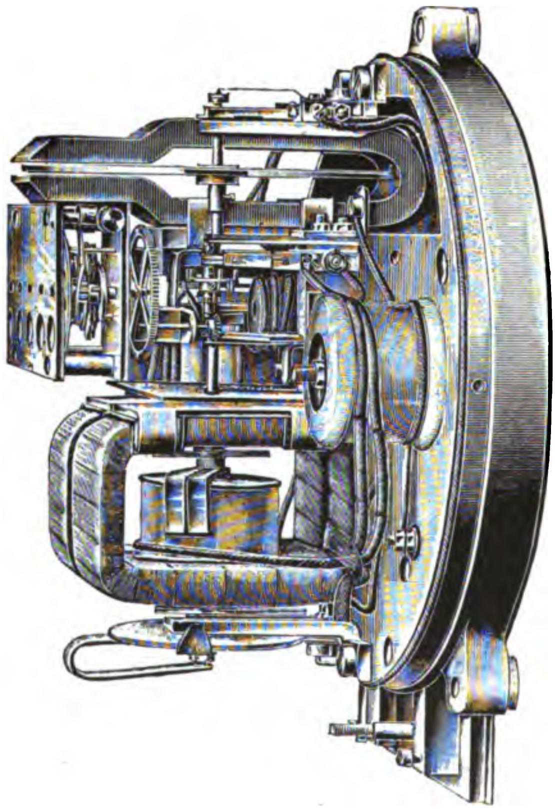

FIG. 68.

Mounted on the commutator axle is a disc, carrying on its periphery a series of pins corresponding in number to the number of commutator segments.

Two semicircular discs are fixed on the armature spindle in line with these contact pins. After a semi-revolution of the armature, one of these half discs engages with one of the pins and rotates the commutator through the width of one segment. This action reverses the current in the shunt coil. As the reverse takes place at the dead point of the armature, its own momentum would not suffice to operate the commutator. A small electro-magnet is consequently used to impart to it an auxiliary impulse. When the armature reaches the reversing point, a contact device, carried on the upper pivot of the main meter axle, places the electro-magnet in parallel with the shunt coil and a portion of the resistance which is in circuit with the latter. The electro-magnet is now energised, attracts its armature fixed to the main spindle, and thus gives the meter armature the required additional momentum to carry it over the dead point and ensure the proper action of the commutator. At the same time it compensates for bearing friction for the

half revolution. This supplemental impulse is given only in the position of minimum torque, whilst in the position of maximum torque the electromagnet exerts no influence on the meter armature. During the greater part of a revolution the armature runs quite free, and the friction of the commutator, when the latter comes into operation, is overcome as explained.

No sparking occurs at the moment of reversal, as practically no current then flows in the shunt coil. The counting mechanism is driven by a worm on the commutator axle, so that any frictional resistance due to it is removed from the main armature spindle.

No compounding or compensating coil, exerting a constant driving torque, is required, as most of the sources of friction are removed from the main meter axle, and are in great part compensated for.

The Deutsch-Russische Direct Current Meter.—The continuous current meter, type E, manufactured by the Deutsch-Russische Elektricitätszähler-Gesellschaft, 19 Glogauerstrasse, Berlin, possesses many novel and characteristic features. The complete instrument, with the cover removed, is illustrated in Fig. 69. Both the shunt and the two main current coils are stationary, and the rotation of the meter spindle is effected by means of a so-called 'reverser' armature, forming a light magnetic needle permanently polarised by the shunt current. The counting mechanism is operated electrically by means of a relay, which, in a manner to be explained later, momentarily causes the reverser armature to return to its initial starting position, when it retraces its path afresh under the action of the main current. The meter spindle carries at its lower extremity a copper brake disc, which revolves between the poles of a permanent magnet and produces the resisting torque to control the speed. The magnet is shielded from the disturbing influence of a short-circuit current by a sheet-iron partition between it and the left-hand series coil. A light revolving element is obtained in consequence of the arrangement adopted, and the friction of the lower jewel is considerably reduced; further, the friction of the counting gear is entirely removed from the meter spindle.

FIG. 69.

No commutator and brushes are employed, so that brush friction is eliminated, and the one rubbing contact of the meter is only in operation momentarily when the relay is energised. Suitable resistances are used in the pressure circuit, and no sparking occurs at the contact.

The principle of the meter will be readily understood by reference to the diagrams given in Figs. 70 and 71.

Referring to Fig. 70, the reverser armature R, energised by the shunt current, rotates on the axle A under the action of the main current in the series coils H H. Theoretically, the armature would be turned through an angle of 180 degrees, from one parallel position to the meter base into the corresponding position, and would then stop. The directive force grows from a zero value, and reaches a maximum in the middle position at 90 degrees, when the shunt coil is at right angles to the main current field; it then falls

off and again reaches the zero value, when the armature is in the parallel position once more. For the operation of the meter only the fourth part of the possible angular motion is used, and in that part of the field $22\frac{1}{2}$ degrees on either side of the maximum. When the armature has turned through these 45 degrees, two platino-iridium contacts C_1 and C_2 come together and close the relay circuit. The one contact is carried by the reverser armature, and the other is attached to the pivoted armature of the relay E, which becomes energised.

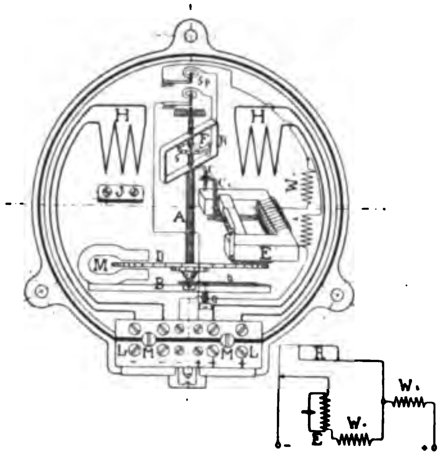

FIG. 70.

The armature of the relay is attracted and rapidly takes back with it the reverser armature R to its initial position. This return motion takes place so rapidly that an ammeter in the relay circuit is unable to follow quickly enough to indicate the current, and no irregularities in the speed of the brake disc can be detected. During the return action the relay circuit is placed in parallel with the shunt coil, and in this moment the magnetisation of the needle is substantially weakened. This effectually facilitates the return of the reverser armature in the main current field.

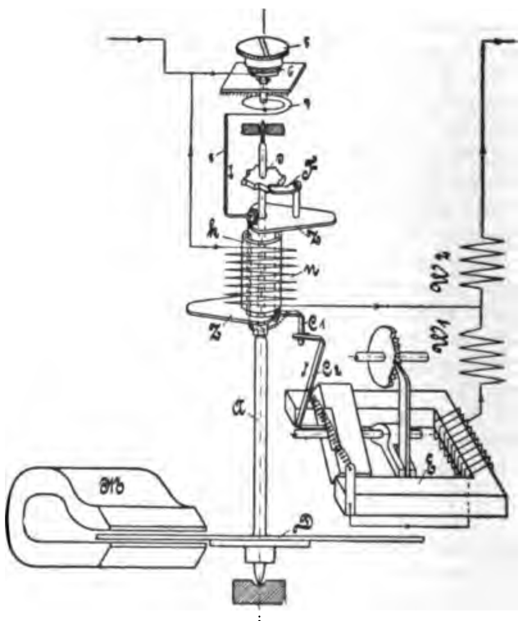

FIG. 71.

When the starting position is reached, contact is broken, and the reverser armature is again turned through half a right angle by the main current and again impinges on the contact. This cycle of operations is then repeated, and the meter integrates continuously the energy consumption. The armature is mechanically coupled to the meter axle A during the forward swing by means of a ratchet and pawl. S is the ratchet wheel mounted on the meter spindle A, and is provided with eight teeth; and F is the pawl attached to the reverser armature. Each time the armature is returned to its starting-point it

gears with the ratchet wheel, and after eight pulsations the spindle, and with it the brake disc D, will complete one revolution. In the actual instrument, as already pointed out, the shunt coil does not move, as its weight would introduce too much friction on the lower jewel. In Fig. 71 is shown diagrammatically at Z Z the reverser armature actually used. It is a thin iron tube having two iron tongues Z Z, arranged the one above and the other below the stationary shunt coil n, which, when energised by the pressure current, polarises it as a magnetic needle, with its magnetisation proportional to the supply voltage. On its upper arm it carries the pawl F, and accomplishes the rotation of the spindle in the manner explained. At each reversal the armature of the relay E drives the integrating mechanism through a ratchet wheel and pawl. Current is led to the contact C_1 by means of the spiral spring '7' (Fig. 71), which, in the actual instrument, is situated above the system near the meter cover, and also serves as a mechanical starting device to compensate for friction at low loads.

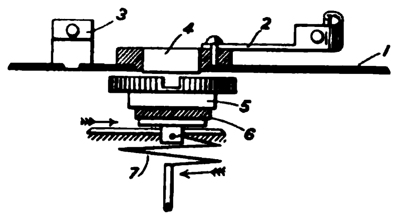

FIG. 72.

A noteworthy feature of the meter is the ease with which this light load adjustment can be made with the meter in position and without removing the cover. Fig. 72 is a sketch of the arrangement. A lever '2' is pivoted on the meter cover '1,' and can be sealed with the sealing screw '3.' By moving the lever on one side the hole '4' in the meter cover is exposed and gives access to the adjusting screw '5,' which is connected to the spiral starting spring '7' by means of the insulating piece '6.' The tension of the spring is altered by the adjusting screw. If the screw be turned clockwise, the spring will compensate for the friction, and the meter will start more readily. If creeping should occur, turning the screw counter-clockwise will prevent this shunt running. Only a very small motion is required, the displacement of the screw-head through one millimetre producing an alteration in the starting of about 1 per cent.

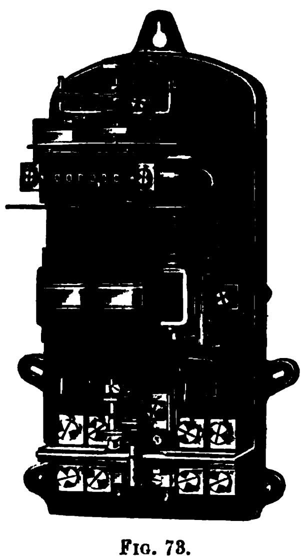
FIG. 73.

The Peloux Meter, manufactured by the Siemens-Schuckert Werke, is illustrated in Fig. 73. Four shunt and two main current coils are used, all of which are stationary. The revolving armature consists of two Z-shaped soft iron cores, mounted together on the meter axle and turned through a right angle relatively to one another. These iron cores are magnetised in turn by each of the four shunt coils. The commutator is stationary, and is supported on an insulated carrier at the top of the meter. It has a contact pin, and is composed of four segments, each of which is connected to one end of a shunt coil.

The brushes are mounted on, but insulated from, the armature spindle and rotate with it. The one brush bears on the commutator and the other on

the contact pin. The remaining ends of the shunt coils are connected together, and their common junction is joined through a suitable resistance to the positive shunt terminal. The negative shunt terminal is connected to the contact pin of the commutator.

The electrical connections of the meter are given diagrammatically in Fig. 74, from which the arrangement of the shunt coils and the Z-shaped armature cores will be readily recognised.

One shunt coil is operative at one time only, and when energised by the shunt current the interaction between its magnetic field and that due to the main current causes the armature to turn through an angle of 90 degrees. Each coil acting in succession will, therefore, cause the armature to rotate continuously.

The work done by the meter is absorbed in the usual magnetic brake. No sparking occurs at the brushes, as each shunt coil has a high non-inductive resistance in parallel with it, as shown in the diagram (Fig. 74), in which the extra current is dissipated on opening the circuit of the shunt coil.

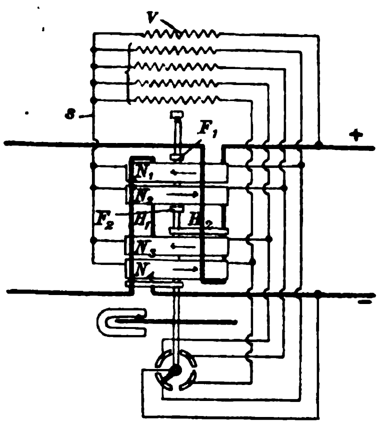

FIG. 74.

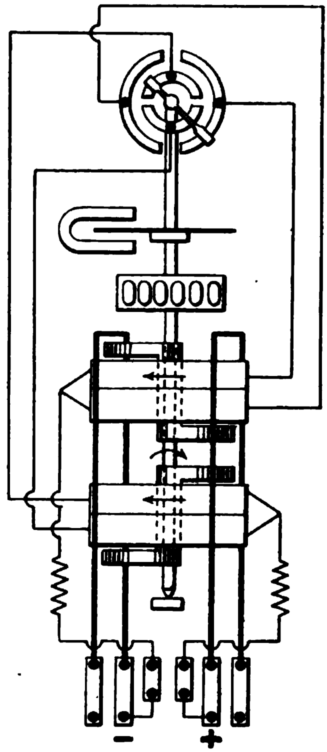

FIG. 75.

These shunt coils are somewhat eccentrically placed round the meter axle, and this eccentricity can be altered, so as to increase or decrease the auxiliary starting torque which this arrangement gives. On account of the use of iron a high driving torque is obtained, and the shunt loss is correspondingly small.

A modification of the electrical connections of the pressure circuit and the commutator is also used, shown diagrammatically in Fig. 75. With this method two shunt coils are always energised in series, by means of which a considerably increased driving torque is obtained, amounting to one and a half times that obtainable with the older method just explained, and the shunt losses are slightly smaller.

The Brush-Sangamo Mercury Motor Meter.—The Sangamo Electric Company, Springfield, Illinois, U.S.A., manufacture a very interesting mercury motor energy meter, which is being placed on the market in this country by the Brush Electrical Engineering Company, London. The chief characteristic features of this meter are the absence of a commutator, brushes, and permanent magnets, the methods employed in adjusting the meter at the high and low loads, and the impossibility of spilling any of the mercury.

The rotating element consists of a heavy copper disc immersed in a mercury bath contained in an insulated chamber, in the lower half of which are imbedded the soft iron poles of the laminated shunt magnet. The shunt flux is produced by two pressure coils wound on the vertical limbs of the shunt magnet, clearly shown at the front of the meter below the integrating train (Fig. 76).

FIG. 76.

The lines of force of the shunt field pass from one pole to the other through a soft plate above the disc, and carried on the upper side of the disc chamber; in this manner the field cuts the copper disc twice in opposite senses. A driving torque proportional to the power is thus exerted on the disc by the interaction of the shunt field with the main current, which flows diametrically across the disc, and which is conducted to and from the mercury bath by copper contact ears imbedded in the disc chamber. These contacts are connected by milled-headed adjusting nuts to flexible leads carrying the main current. The retarding torque, proportional to the speed, is produced by the same shunt flux, and the usual permanent magnets are dispensed with for this purpose. It will be seen that the retarding torque is proportional to the square of the voltage, so that pressure variations above and below the normal affect the accuracy of the meter. This company supply a voltage regulator to compensate for any voltage fluctuations. It consists of a small electromagnetic device at the back of the disc chamber, and it compensates for the voltage fluctuations by automatically varying the distribution of the main load current between the armature and a shunt round the disc box.

The regulator is, however, not embodied in the meter, as the Sangamo

Electric Company have not found it necessary to use it on the average constant-pressure direct-current supply circuits in America, and these meters are all calibrated at the average normal voltage for which they are to be used.

The disc is mounted on a shaft, the revolutions of which are conveyed to the integrating train in the usual manner. Owing to the upward pressure of the mercury on the disc, the shaft is slightly counterweighted. The weight used is less than the upward thrust on the disc, so that there is always a slight upward pressure against the flat jewel in the upper bearing of the meter. This upper bearing is furnished with a fine screw adjustment to give the disc the requisite amount of lift. A series compensating coil, wound on the bottom yoke of the shunt magnet (Fig. 76), is used to compensate for mercury friction at the full load speeds.

The heavy load adjustment is made by altering the position of the milled headed connecting nuts on the copper disc ears (Fig. 77). This alters the distribution of the current in two paths in the disc, producing different torque effects.

A novel light load or friction compensation is used. A portion of the pressure current is shunted through the armature disc by means of a high-resistance rod, which is connected between the two main current terminals of the meter, and on which is a sliding connector, joined to one end of the pressure coils in series with one another, the other end of which goes to the shunt terminal below the shunt magnet. By varying the position of the slider, the value of that part of the pressure current which traverses the armature disc is altered, and so the supplemental torque which this current exerts with the shunt field may be adjusted for light load friction. It will be seen that a very convenient, rapid, and accurate adjustment is obtained, giving a range from zero up to the maximum torque produced by the shunt current flowing through the disc.

FIG. 77.

The whole of the main current in the 5 and 10 ampere sizes flows through the disc and series compensating coil. In the large capacity meters a shunt resistance is used, so that only a definite proportion of the total current traverses the disc. In a 25 ampere size, 10 amperes pass through the disc at full load and the remainder through the shunting resistance. For currents exceeding 50 to 100 amperes, the current shunt is supplied in a separate cast-iron box.

At the opening in the disc chamber through which the spindle passes to the upper bearing is a pocket which surrounds the opening. When the meter is turned upside down the mercury runs into this pocket, so that it is impossible for it to be spilled, and when it is again placed in the upright position the mercury returns to the disc chamber. The speed of the meter is readily checked, as the rotation of the armature is indicated by a small hand attached to the shaft (Fig. 77), above the aluminium cap on the disc chamber, and can be easily observed through a small window in the top of the meter case.

Chamberlain & Hookham Mercury Motor Meter.—Messrs Chamberlain & Hookham, Ltd., Birmingham, also manufacture an energy motor meter of the mercury type, the armature of which is similar to that used in thei 1902

Fig. 78.

ampere-hour meter. It consists of a copper cylinder immersed in a mercury bath, contained in a chamber bored out of an ebonite block, in which are imbedded the two conducting strips by which the current is led to and from the mercury. The torque is produced by the interaction of the magnetic field of a shunt electro-magnet with the main current flowing in the armature.

The electro-magnet consists of a straight core, which is built up of a series of iron washers, with insulation between them. The core carries the shunt energising coil and terminates in a soft iron pole-piece, which projects up inside the armature and supports the bottom pivot of the spindle, on which latter is mounted an aluminium brake disc.

The disc rotates between the poles of a couple of permanent magnets, and produces with them the retarding torque proportional to the speed. The shunt magnet has only one pole-piece, there being no external pole outside the armature. The lines of force return to the magnet core through the air, so that the flux produced may respond effectively and rapidly to changes in voltage.

In Fig. 78 is given an illustration of the switchboard type for currents above 50 amperes, provided with a separate shunt.

CHAPTER VI.

CONTINUOUS CURRENT METERS FOR SPECIAL PURPOSES.

Section A.—Battery Meters.

THE charge and discharge of a storage battery are measured by means of ordinary continuous current quantity or energy meters. Preferably, quantity

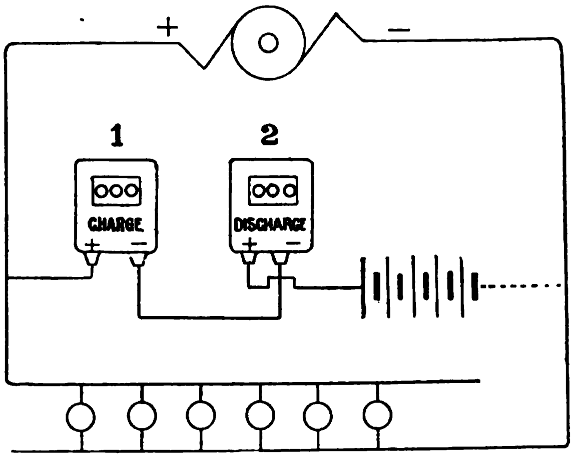

FIG. 79.

meters reading in ampere-hours should be employed, as the principal feature in connection with a battery is its capacity. It is most important to have a continuous indication of the actual condition of a battery, as furnished

generally by its capacity, at once giving not only the amount of current available for further use, but for what length of time at a given discharge rate. It is not so necessary to know the energy of the input or the output.

Two-meter Battery System with Ratchet and Pawl.—Various methods are in vogue to effect these measurements. One very general method is to use two ordinary meters, permanently connected in series with the battery. The one meter registers the charge and the other the discharge, each being fitted with a ratchet and pawl attachment which allows the meter to rotate in one direction only, and prevents it from running backwards when the current is reversed in its series circuit. The current flows oppositely directed in the series circuits of the two meters, so that with this arrangement one only can

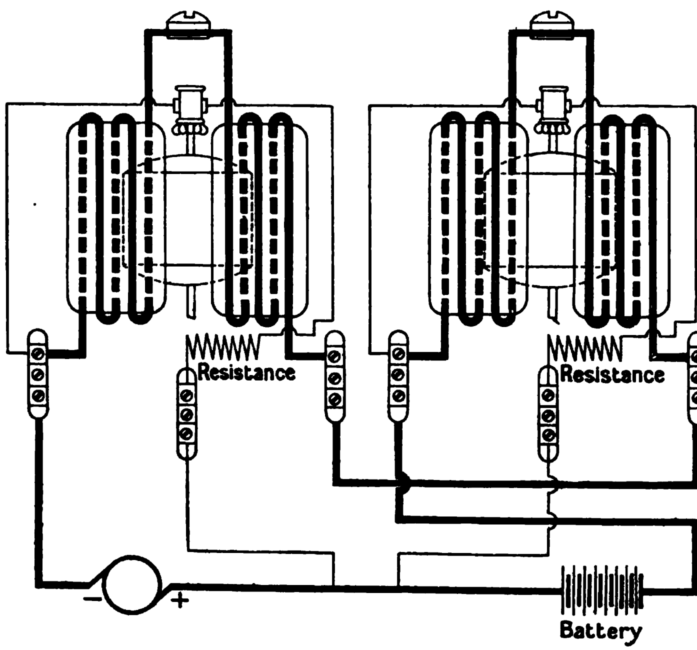

Fig. 80.

work at a time, according as the battery is being charged or is discharging. When energy meters are used in this manner their pressure circuits are so connected that the currents flowing in them are always in the same direction, and are not reversed with the reversal of the current in the main coils. This method is in use by Messrs Chamberlain & Hookham and the British Thomson-Houston Company, with their respective types of meters. Fig. 79 gives diagrammatically the connections of the Hookham meters, and those of the Thomson meters are shown in Fig. 80. The meters are calibrated to read direct in ampere-hours.

The Electrical Company's Two-meter Method for battery work is illustrated diagrammatically in Fig. 81.

The meters, it will be seen, are permanently connected in series, but the current flows in their series circuits in the same direction, and not oppositely

directed as in the previous method. The pressure terminals of the meters are also differently connected to the circuit. In addition, no pawl and ratchet attachments are used on these meters, which consist of this company's ordinary oscillating G type. This results at once from the principle of the action of the meter, described in Chapter V. The meter only works when the current in the series coils and, therefore, their magnetic fields are in the correct direction with reference to that of the shunt current and its magnetic field. The explanation is quite simple. The moving coil consists of two half windings, each of which is operative at one time only, and in successive half oscillations. The two windings are, moreover, always oppositely polarised relatively to one another by the shunt currents.

If we assume, for the sake of illustration, that when traversed by the shunt

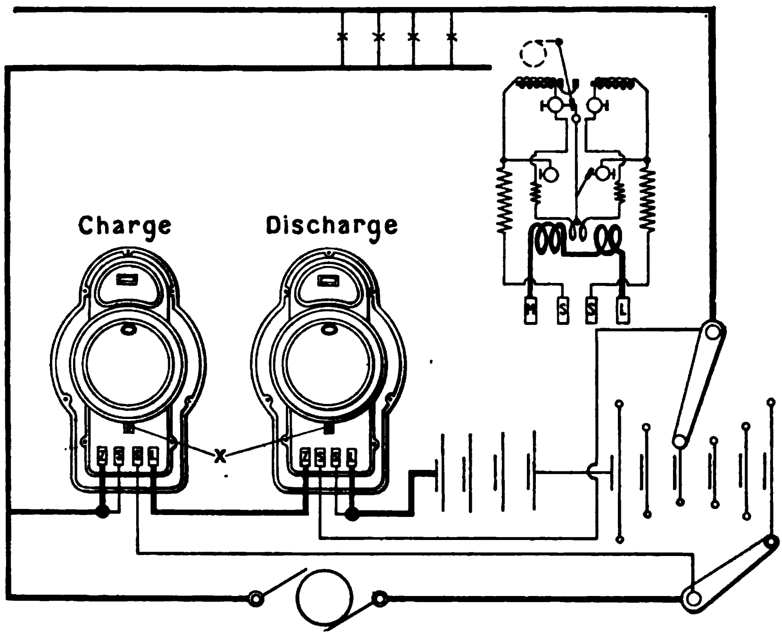

FIG. 81.

current the left-hand winding of the swinging coil becomes polarised, so that its left-hand face acts as a *south* pole and its other face as a *north* pole, then the other winding, when it is in turn energised by the current, will be polarised in the reverse order. In this case, for the meter to work, the main current must flow in the two stationary coils in such a direction that *each* acts as *north* pole in relation to the swinging system. The swinging coil will then oscillate backwards and forwards. If, however, either the shunt or the main current be reversed, but not both simultaneously, the meter will not work.

If we reverse the main current, then *each* stationary coil now acts as a *south* pole, and the swinging system can only move into either one or other of the two extreme positions, when it will stop. If, of course, it happens to be in one of these limiting positions, it does not move at all.

Hence, with two of these meters arranged as shown in the diagram (Fig. 81), one only will register the charge and the other the discharge, the direction of the current to or from the battery determining which meter will register, as either cannot do so until its magnetic fields are of the correct polarity. The meters register either in kilowatt-hours (B.O.T. units) or in ampere-hours as may be required ; if the latter be desired, the pressure circuit of each meter is put across a source of constant or nearly constant E.M.F., such as the lighting bus-bars, and the meter is calibrated to read direct in ampere-hours at that pressure.

British Thomson-Houston Company's One-meter Battery Systems.—Another method which is often used is to employ only one meter. If, however, it be of the energy type, and be fitted with a friction compensating device, this has to be removed. The reason for removing the compensating coil is that, if the battery be discharging, the field set up by the compounding coil would oppose that due to the main coils, and thus cause the meter to register less than it should. This method is not one to be recommended, as the meter does not read accurately at low loads; in addition, as there is only one dial, if the reading be not taken as soon as the charge is finished, no complete record of the discharge can be kept. With an ideal battery giving

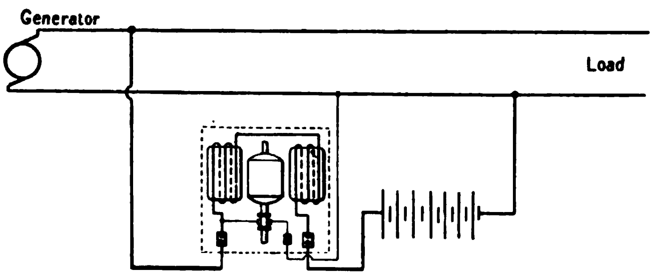

Fig. 82.

an efficiency of 100 per cent. the dial of the meter returns to zero as the battery discharges, and in any position indicates the exact amount of energy available. It, moreover, points to zero when the battery is discharged, assuming an initial zero reading. A diagram showing the connections of a Thomson meter in this case is given (Fig. 82), and the meter will run in either direction according to the direction of the current. A modification of this method is used by the British Thomson-Houston Company, and is also illustrated in Fig. 83. The meter is fitted with a compensating coil as usual, and the arrangement, as regards accuracy, is quite as satisfactory as the two-meter system, but there exists the same difficulty in connection with the readings of the dial. The reason why a compensating coil can in this case be used is that the current is not reversed in any part of the meter.

It will be seen that the meter revolves always in the same direction whether the battery is being charged or is discharging, and, in consequence, the dial, instead of returning to zero, sums up the various charges and discharges. Hence, as in the previous case, it is necessary to read the dial before and after each charge and discharge.

Referring to Fig. 83, it will be seen that four different combinations can be obtained. The generator will feed the bus-bars only when the single-pole double-throw switch C is open and the double-pole single-throw switches A

and B are closed. When the generator is to feed the batteries only, then switch B is opened, A is closed, and C must be moved on to contact No. 1.

When the battery is discharging and the generator is shut down, C is on contact No. 2, A is open, and B is closed. To run both the battery and generator in parallel, both A and B must be closed, and C is placed on contact No. 1 or No. 2; and if on No. 1, the discharge of the battery will not be registered by the meter.

In all other cases the current flows in the meter; and when the battery and generator are in parallel with the switch C on contact No. 2, the meter will register the combined output.

The Aron Battery Meter.—The Aron Electricity Meter, Limited, employ the one-meter system in connection with their two types of battery meters, which are Dr Aron's double dial meter and the Miller reversible meter. In each case the instrument is exactly the same as the ordinary Aron house-

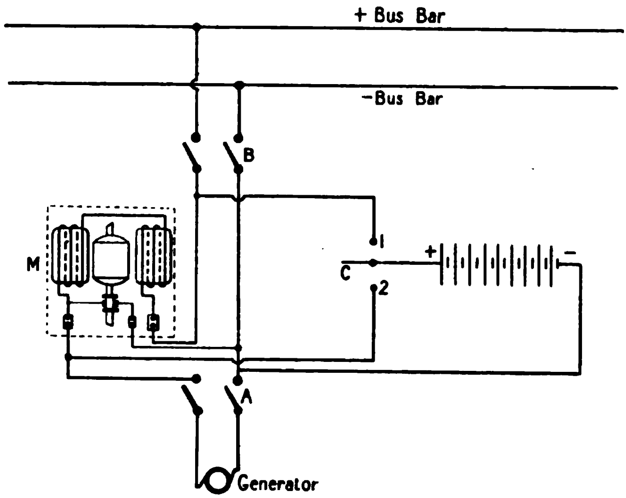

FIG. 83.

supply type as regards the electrical and clockwork mechanisms. As already explained in a former chapter, the main actuating axle of the counting train revolves at a rate depending on the difference in speed of the two pendulums, and the direction of rotation of this axle depends on the electrical arrangement of the shunt and series systems. If the current in either one of these be reversed in direction, the direction of rotation of the main axle will also be reversed, so that the ordinary meter placed in a battery circuit will record one way during the charge, and in the opposite during the discharge. The records would therefore be destroyed.

In the double dial battery meter illustrated in Fig. 84 a system of ratchet gear is inserted between the main axle and two counting trains, any movement in one direction actuating the one train, while that in the opposite drives the second train.

In this manner the charge is always read from one set of dials and the discharge from the other set. When the readings are to be in ampere-hours the shunt circuit of these meters must be always connected to a constant

potential circuit which is never reversed in direction, and their accuracy depends on the constancy of voltage of the shunt circuit. In practice, an ordinary lighting circuit well within the Board of Trade limit serves the purpose very well. If, however, the voltage be permanently too high or too low, the meter will run too fast or too slow in exact proportion to the voltage variation.

In the Miller reversible meter, Fig. 85, an ordinary Aron instrument is used with one large round dial and one pointer instead of a series of counters. It has no ratchet gear, and the record made in discharging is destroyed during the charge.

FIG. 84.

FIG. 85.

The instruments are generally fitted with a relay, which automatically inserts a resistance in series with the shunt circuit, so that the meter runs more slowly on the charge than on the discharge by an amount corresponding to the difference between the charge and discharge ampere-hours, so that, when the pointer is brought back to zero, it indicates that the battery is fully charged. When the battery is discharging, the pointer revolves clockwise.

The Deutsch-Russische Battery Meter.—The battery meter of the Deutsch-Russische Elektricitätszähler-Gesellschaft is illustrated in Fig. 86, and is a combination of two of their reverser armature systems operated upon by one main current coil. Each armature system is complete in itself, and is provided with an independent magnetic brake and counter, the one registering the charge and the other the discharge. One only of the two systems is influenced at any one time by the passage of a current in the series coil, and no mechanical

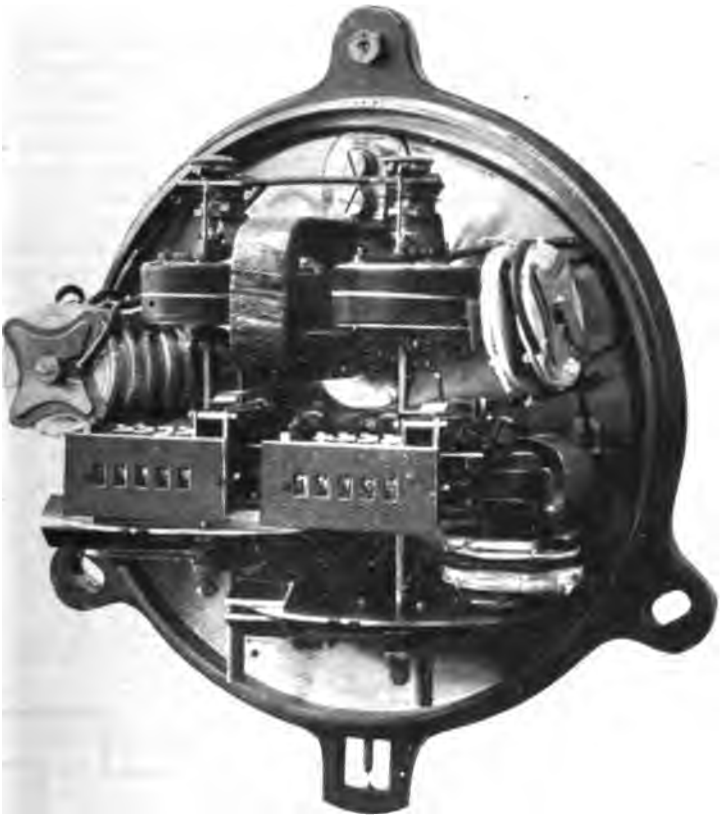

FIG. 86.

coupling between them is required. This follows at once from the principle of the meter, described on page 83.

The magnetic field produced by the main current causes the one reverser armature to pulsate during the charge and to register, holding back the other, which is oppositely polarised. When the current is reversed, the first armature will be prevented from moving, and the other will now be made to pulsate and register the discharge.

The O'K. Battery Meter.—The Compagnie pour la Fabrication des Compteurs, Paris, slightly modify their O'K. ampere-hour meters when intended to measure the charge and discharge of a battery of accumulators.

Only one meter is used. The small electric motor of this meter, as already explained on page 43 in Chapter III., is connected as a shunt to a resistance which carries the whole current to be measured, and which is mounted on the base-plate of the meter itself. In this case, however, the resistance forms a separate piece of apparatus and is furnished with a sliding contact. It is specially designed to produce a maximum difference of potential of about ·25 volt. The arrangement adopted is shown in Fig. 87. The terminals E and F of this resistance are connected to those of the meter marked R and T. The armature of the latter will rotate from right to left when the cells are being charged, and in this case the current only partially traverses the resistance, going along the path from C to B. When the cells are discharging, the direction of rotation of the meter will be reversed, and the current will flow through the whole resistance from B to A. The meter, in addition to the ordinary set of dials, has a large dial graduated in ampere-hours. When the cells are charging, the pointers of the small dials do not move; the pointer of the large dial, however, turns counter-clockwise and indicates in ampere-hours the quantity of electricity put into the cells, reduced in the ratio of the efficiency of the battery.

On discharging, this pointer revolves back, giving at every instant the available capacity of the cells; and the amounts of the discharge are continuously integrated on the small dials, the pointers of which are now free to move.

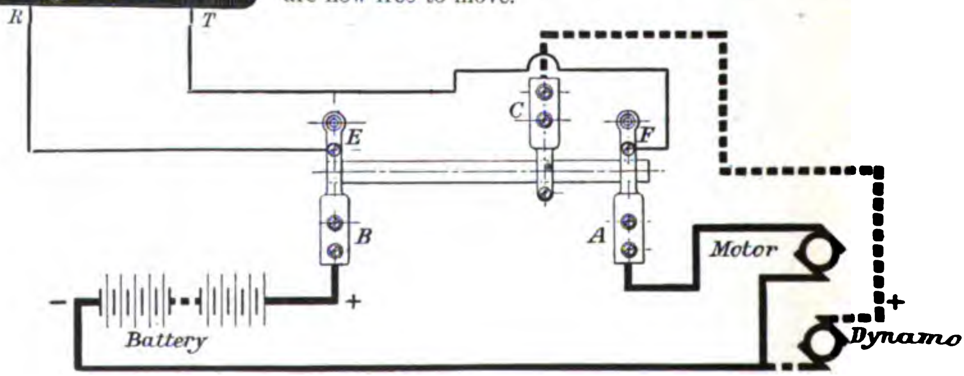

Fig. 87.

By means of the sliding contact C, the ratio of the resistances of the two branches B C and B A can be adjusted until it is equal to the ampere-hour efficiency of the battery. When this condition is fulfilled, the large pointer always indicates the quantity of electricity which can be taken out of the battery.

This system can be advantageously used with electric automobiles; and the counting train can be arranged with a contact system operating a relay circuit, which will automatically interrupt the charging current when the battery is fully charged.

These battery meters are made in three sizes for charging capacities of 100, 200, and 400 ampere-hours.

In each case the large dial is divided into 100 parts, each division of which corresponds to one, two, or four ampere-hours, according to the capacity of the meter. Similarly, each unit on the first of the small dials reads ten, twenty, or forty ampere-hours. An exactly similar arrangement is adopted by the Danubia Actiengesellschaft also with their O'K. meters.

The Siemens-Schuckert Battery Meters consist of the company's ordinary continuous current types, each of which is fitted with two separate counters and a change-over device. The one counter registers the charge and the other the discharge, and a small index on the dial face indicates the one which is working, and whether the battery be supplying or receiving current.

The connection between either counter and the meter spindle is made by a movable lever, on the one end of which is mounted a worm and on the other a worm wheel, which gears with the worm on the meter spindle. According to the direction of rotation of the meter, in one direction on the charge and in the opposite direction on the discharge, the worm wheel causes the lever to move upwards or downwards and the worm to gear with a corresponding wheel of the respective counting train, thus bringing the latter into action. Fig. 88 is an illustration of the Peloux meter manufactured by this company, and fitted with two counters and a change-over arrangement for battery purposes. The meter is also shown with a special set of test terminals.

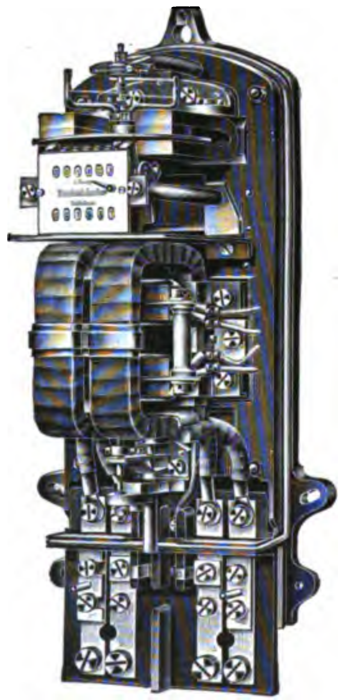

FIG. 88.

Section B.—Switchboard Meters.

For the measurement of the output of direct current lighting, power, and traction systems, special switchboard instruments are used. They retain the principles common to their respective types, but are variously modified to comply with the severe conditions of heavy and fluctuating loads obtaining in central stations in general. Precautions have also to be adopted to shield the meter from the influence of the magnetic fields set up by neighbouring bus-bars or heavy-current cables.

Hookham type.—Two methods are in vogue. In the one the meter is supplied with a high-capacity shunt traversed by the whole current, and potential leads connect the current circuit of the meter to the terminals of the low-resistance shunt, so that the current flowing in the meter is always a determinate fraction of the main current in the bus-bars or feeder circuit. This method is, however, mainly restricted to quantity meters. An illustration of the Hookham ampere-hour meter for 2000 amperes, with its shunt, is shown in Fig. 89, and may be taken as typical of this class of heavy-current shunted meters. The current in the meters is in this case about 50 amperes.

For switchboard work, the meter is separated from its shunt, and the latter is mounted on the back of the board, while the meter is fixed on the front.

Thomson Switchboard Meters.—In the other method, a construction is adopted in which the whole current passes through the meter itself. In this manner any errors due to the use of a high-capacity shunt are eliminated. In the Thomson meters the entire current flows through the field coils, which, fôr heavy currents exceeding 1500 amperes, consist of a single heavy bus-bar of forged or cast copper of high conductivity. It will be remembered that in

Fig. 89.

the ordinary Thomson meter one armature connected to the pressure circuit is used. In this case, however, two armatures connected together in series are employed, and are oppositely wound. They are arranged astatically, the one above and the other below the bus-bar of the meter, so that they are cut in opposite senses by the magnetic field produced by the current in the bus-bar, and both, therefore, tend to rotate in the same direction,

The damping magnets are enclosed in a cast-iron box. This construction

ensures practical freedom from stray fields and bus-bar effects. The entire meter is supported upon the switchboard by two studs, which form at once the electrical connections and the mechanical support.

The astatic switchboard types for heavy currents of the British Thomson-Houston Company, Rugby, and the General Electric Company, U.S.A., are respectively illustrated in Fig. 90 and Fig. 91. Noteworthy differences exist between them, mainly in the construction of the armature and compounding coil, and in the number of coils used. In the meter of the British Thomson-

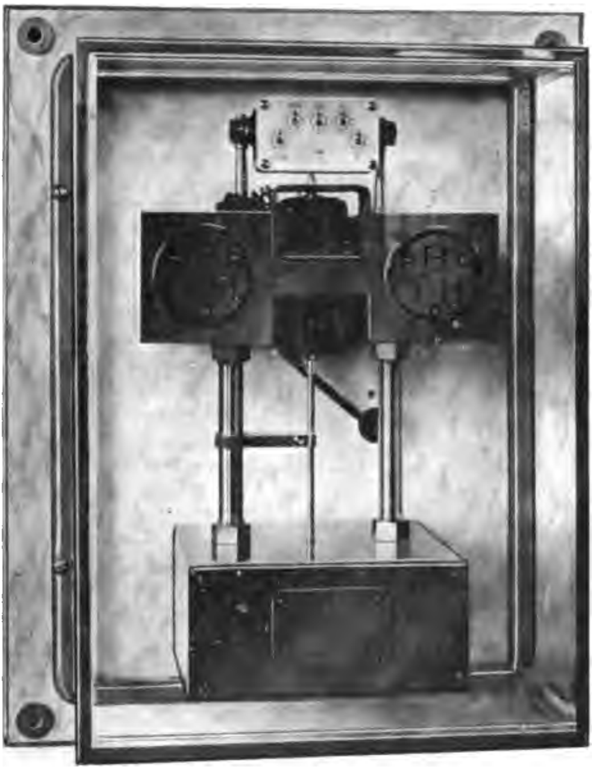

FIG. 90.

Houston Company, not only are two armatures used, but each has its own commutator and a stationary core composed of iron washers; further, the armatures, each consisting of two coils, are in planes at right angles to one another. The compensating coil consists of a few turns of fine insulated copper wire acting on the upper armature, as shown in the illustration, Fig. 90. This type of compensating coil is, however, only used in meters intended for extra heavy currents and furnished with the square copper studs.

The meter of the General Electric Company, U.S.A., has only one commutator, and the two armatures do not materially differ from the ordinary drum-wound type; they are oppositely wound and contain no iron. Two

compensating coils are used, and are clearly shown in front of the two armatures in the view given in Fig. 91.

In the switchboard meters of the British Thomson-Houston Company for capacities from 600–1200 amperes, the two armatures are exactly as in the larger sizes; the magnets are also encased in a shielding box, but two field coils are used and a different form of compounding coil. An illustration of their 800 ampere size is given in fig. 92, from which the general arrangement will be readily gathered.

The field coils consist practically of four parallel horizontal copper bars; the two outside bars are connected to the left-hand stud and the two central bars to the right-hand stud. The free end of each horizontal bar is connected to a vertical bar, and the vertical bars are all united at the top by means of a horizontal hood. The main current, in passing from one stud to the other, splits up into two halves, and each half traverses two horizontal bars, the current in all the horizontal bars flowing in the same direction. In this manner the effect is the same as two complete turns, each traversed by the whole current, and in the particular meter illustrated is equivalent to 1600 ampere-turns. The field coils are not actually made up of separate bars (merely given to illustrate the effect), but consist of a single copper casting or forging of special construction to give this effect. The two armatures are arranged astatically above and below the horizontal bars, and the hood portion produces very little, if any, effect on them. The compensating device is placed at the back of the field coils, and is a vertical coil of fine insulated copper wire in the armature circuit. The coil is wound on an iron core, made in two halves. The two halves can be screwed apart to increase or decrease the air-gap between them. This action alters the magnetic reluctance of the coil, and so regulates the supplemental torque it exerts on the armatures. With this design of the field coils and the use of iron in the armatures all their switchboard meters can be arranged as astatic meters for currents as low as 600 amperes.

Fig. 91.

In Fig. 93 is shown diagrammatically a Thomson three-wire switchboard meter for 600 amperes made by this company. In this type the field coils consist of two bus-bars; the one is placed in the positive outer and the other in the negative outer of the system, and they are so connected that the currents in them flow in the same direction. Two armatures, with two commutators astatically arranged, are used, as in the other types, and the pressure circuit of the meter is connected direct across the three-wire network as shown.

The Aron Switchboard Meter presents no new features over the ordinary instrument beyond the alteration of the main current coils, which for heavy currents are replaced by a single bus-bar, and this type of coil is used in all instruments for currents exceeding 300 amperes. The bus-bar has transverse slots in it, running from opposite sides, so that the current flowing in it circulates clockwise round one slot and counter-clockwise round the other, in

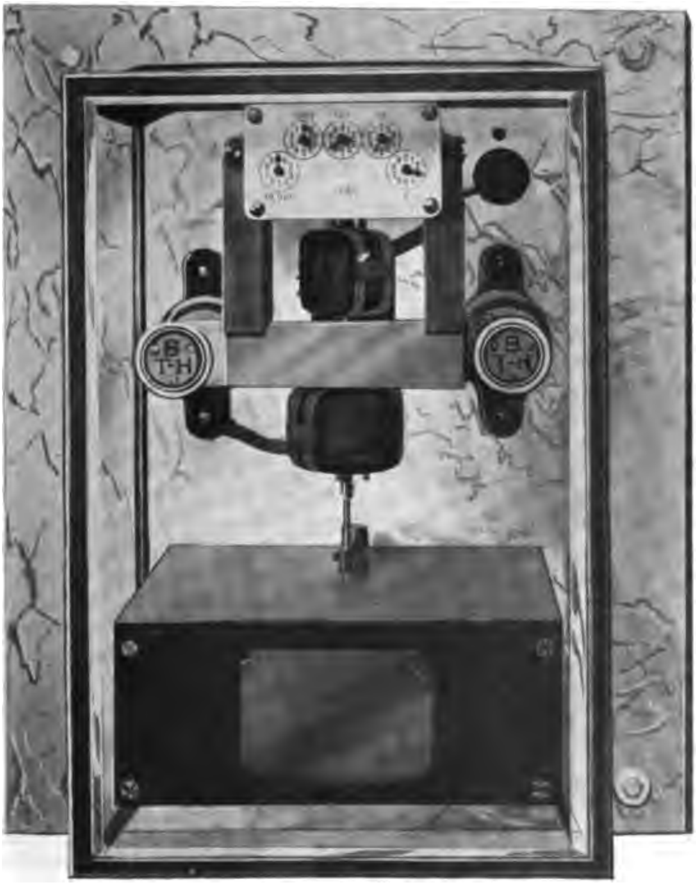

FIG. 92.

order to obtain the necessary reversed fields to operate the potential coils of the pendulums. This is clearly shown in Fig. 94, which represents a line drawing of the type of heavy current bus-bar used by the Aron Electricity Meter, Limited. The pendulums oscillate in the usual manner above the bus-bar, and are symmetrically suspended above the two holes in the same.

The Electrical Company's Switchboard Meter.—The modifications introduced by the Electrical Company into their oscillating meter are easily recognisable from the illustration of their switchboard and traction type given

in Fig. 95. The counting mechanism, peculiar to this meter, is constructed as a separate instrument, and can be mounted direct on the switchboard, while the meter itself is placed at some convenient point in the main circuit.

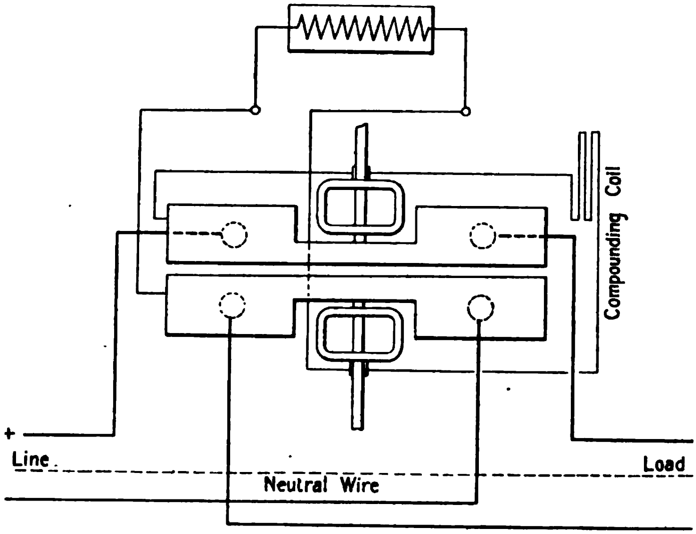

Fig. 93.

The two parts are placed in electrical connection with one another by a flexible cable consisting of five wires of small diameter. A considerable saving of space may hereby be effected on the switchboard, a consideration of some importance. The main current coils are now made of a single massive copper casting, or of two castings, forming in either case two half turns in opposite directions.

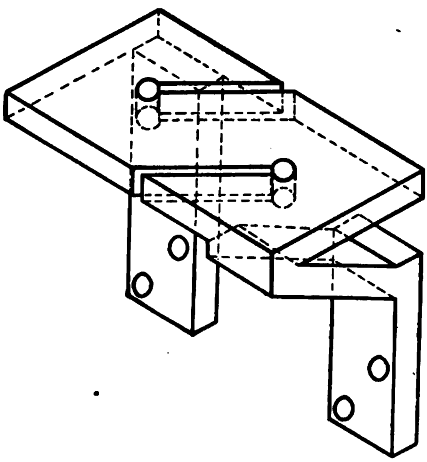

Fig. 94.

The armature consists of two shunt coils interconnected, and each coil oscillates in the field of one of the half turns. The construction renders the meter astatic and independent of external magnetic influences.

The Siemens - Schuckert Switchboard Meter. — For large currents and switchboards the Siemens-Schuckert Werke use their GW type of direct current meter, illustrated in Fig. 96. The general arrangement of the constituent parts of the meter will be easily followed from the illustration, which also clearly shows the method of supporting the adjustable compensating coil. This company, in addition to the above type, also supply for switch-

board use their direct current ampere-hour and watt-hour meters, based on

FIG. 95.

the principle of intermittent registration. The meter is simply either an ammeter or wattmeter, combined with an electrically driven clock mechanism, which actuates at intervals of about $3\frac{3}{4}$ seconds an integrating counter.

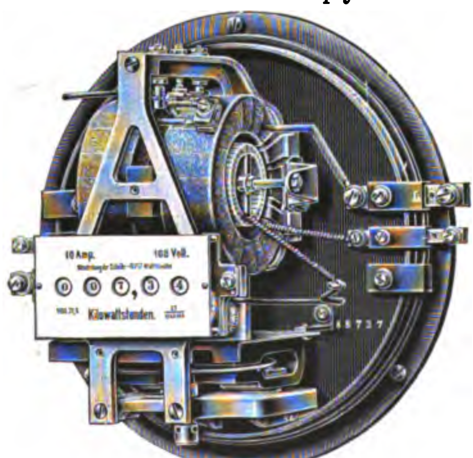

FIG. 96.

In the ampere-hour meter the ammeter proper is of the moving-coil permanent-magnet type, and in the watt-hour meter the field is produced by an electro-magnet energised by the pressure current. In the latter type the clock mechanism momentarily causes a contact to short-circuit the coils of the electro-magnet just before the counting train is actuated. In this manner the reading registered always corresponds to a point on the rising part of the magnetisation curve of the iron, and errors due to hysteresis are eliminated. These errors would otherwise result from the readings being taken at one

time on a rising and at another time on a falling voltage. The meter is provided with a scale and pointer in addition to the dials, which register in the usual manner the units consumed. The scale is graduated in amperes or watts according as the instrument is constructed as an ampere-hour or watt-hour meter.

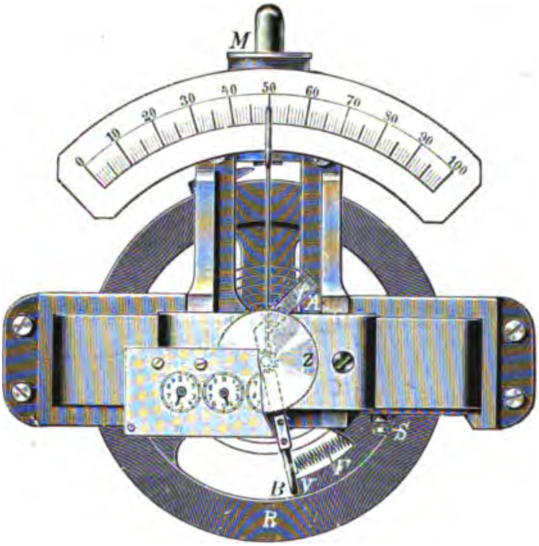

FIG. 97.

The clock mechanism (Fig. 97) consists of a heavy balance wheel R, which receives periodic impulses from the electromagnet M energised by the pressure current. The counting train is worked by a disc Z having a serrated edge, over which a small spring is continually moved to and fro by the balance wheel. When the spring is moving in one direction it does not touch the disc, but on its return swing meets a projection on the pointer of the ammeter or wattmeter, which causes it to engage with and turn the disc through an angle corresponding to the deflection of the pointer. At the same time the pointer is carried back to zero, in which position it is disengaged from the disc and is again free to move, when the disc also remains stationary.

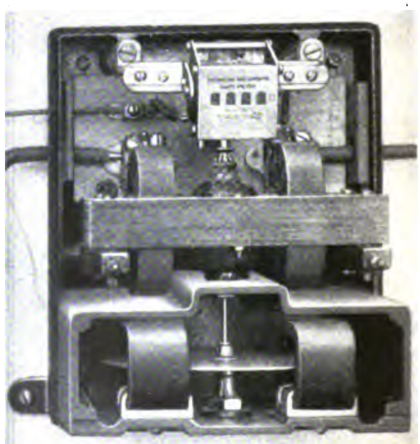
FIG. 98.

These operations are repeated at every swing of the balance wheel, so that every $3\frac{3}{4}$ seconds the deflections corresponding to the amperes or watts are integrated by the counter. The motion of the pointer is an indication of the correct working of the clock. The instrument is used with an ordinary ammeter shunt, so that it is unnecessary to provide a special shunt if one of the correct capacity should already exist on the board. It must, of course, be calibrated with the shunt to which it is connected.

Section C.—Tram-car Meters.

General.—For tram-car work, meters have also to be specially constructed to meet the arduous conditions imposed by this class of service. The difficulties incident to making a reliable and accurate meter for permanent installation on tram-cars are mainly of a mechanical nature. At the same time the electrical requirements are not easy to fulfil, as the meter must be capable of withstanding not only overloads greatly in excess of its normal capacity for brief periods, but also an overload of at least 25 per cent. almost indefinitely.

The function of the tramway meter is not only to register the amount of energy consumed per car, but also to act as a check on the handling of the car on the part of the motor man, and to give an indication of the condition of the electrical equipment. The careless manipulation of the controller and brake is a matter of serious importance, resulting in a considerable loss of energy.

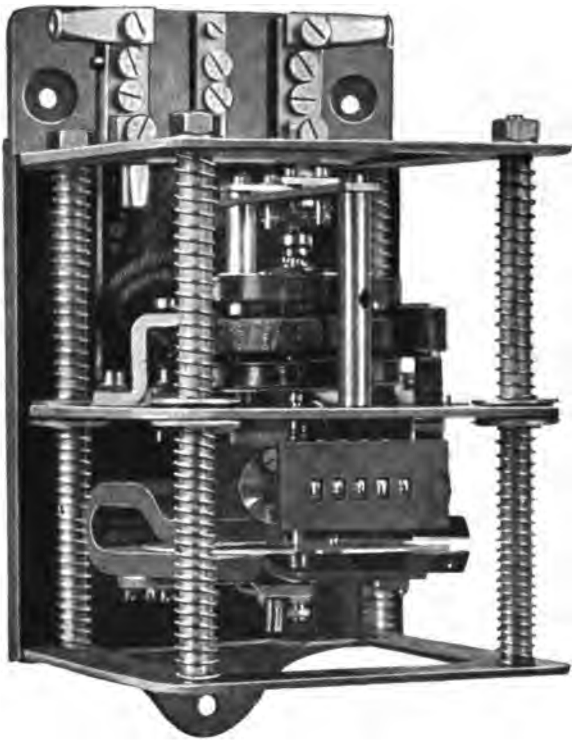

FIG. 99.

By properly recording the actual energy taken by the cars and keeping records of the motor men, a saving amounting from 10 to 20 per cent. of the total used can be effected. Taking a very conservative estimate of the saving, the car capacity of a traction system could be increased by about 10 per cent. with the same energy output from the station, and the company's receipts increased in direct proportion to the energy saved. Of course, the actual amount saved depends on the physical character of the track. A level track will not require the same skill and management as one with several grades and curves.

Thomson Tram-car Meter.—Fig. 98 is a view of the Thomson meter specially designed for tram-car work. It differs in many essential details from the standard Thomson pattern. A soft iron armature core and laminated iron fields are used. The armature core is stationary, and only the winding revolves. This arrangement gives a high torque with a light moving element, and reduces the weight on the footstep bearing, which for this work consists

of a spring-seated diamond jewel. The meter is thus enabled to more readily withstand the severe vibrations and jars to which it is subjected. The resistance of the armature winding is about 30 ohms, and has a high resistance of 10,000 ohms, in series with it. This gives a drop of about 1·5 volts across the brushes, so that the liability to spark is considerably reduced.

The brake system is completely enclosed in the cast-iron box at the bottom of the meter case, and is effectively shielded from the effects of the varying currents in the motor.

For tramway purposes the Bastian Meter Company use their ordinary electrolytic meter, enclosed in a special case fitted with a cast-iron top, by which it is screwed to the canopy of the car.

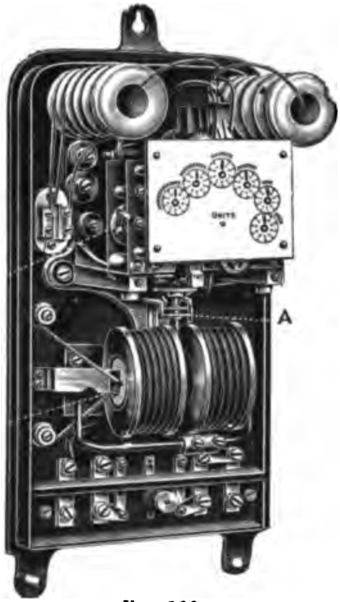

Fig. 100.

Deutsch-Russische Tram-car Meter.—The Deutsch-Russische Elektricitätszähler-Gesellschaft employ their ordinary meter, suspended by springs in the manner illustrated in Fig. 99. The meter is fixed on a horizontal carrier which rests on four supporting springs. Vibration in a vertical plane due to shocks and jars is prevented by four vertical damping springs, and any lateral vibration is taken up by flat spiral springs let in the holes for fixing the carrier.

Aron Tram-car Meter.—The modification introduced into the Aron meter for use on tram-cars will be seen from the illustration given in Fig. 100. The differential clock is regulated by means of balances instead of pendulums. The one balance B is controlled by its hairspring only, while the other one A carries the pressure coils and is electro-magnetically acted upon by the pressure current and the main current in the stationary coils. These are placed with their axes horizontal, so that the pressure coils attached to the second balance spindle may oscillate between them.

To eliminate all possibility of creeping, due to vibration or any other cause, an auxiliary shunt coil C is used, the action of which is to tend to drive the meter backwards. It is fixed within the left-hand main coil. Any backward motion is, however, prevented by a pawl on the first counting wheel.

When no current flows in the main coils the balances beat in synchronism, but as soon as current is taken, the rate of oscillation of the balance with the pressure coils is changed, and the difference in speed of the two balances, which is proportional to the power, is integrated by the clock train and registered on the dials in B.O.T. units. The meter is suspended on springs.

CHAPTER VII.

GENERAL PRINCIPLES OF SINGLE-PHASE AND POLYPHASE INDUCTION METERS.

Single-phase Alternating Current Power and Energy—Rotatory Magnetic Field—Rotating Vectors — Law of the Induction Meter — Inductive and Non-inductive Loads— Behaviour of Three-wire Single-phase Induction Meters—Measurement of Polyphase Power — Equations of Power for a Three-phase Three-wire Star System — Equations of Power for a Three-phase Three-wire Delta System—Two-Wattmeter Method of Measuring Polyphase Power—Two-phase System—Equations of Power for a Three-phase System with Four Conductors — Comparison of Equations for Three-phase Systems with Three and with Four Conductors.

Single-phase Alternating Current Power and Energy.—In an alternating current circuit both the current and the voltage are changing in sense and magnitude from instant to instant in a periodic manner, and are generally sine functions of the time. If c and v denote the instantaneous values of the current and voltage, C_0 and V_0 representing their maximum values respectively, n be the frequency of the alternating current or voltage, and ϕ be the angle of phase difference between the current and the pressure, then

$$v = V_0 \sin pt,$$
$$c = C_0 \sin (pt \pm \phi),$$
$$\text{where} \qquad p = 2\pi n.$$

The instantaneous value of the power is $c.v$, and the mean power P during the whole periodic time T of one cycle is given by the equation

$$P = \frac{1}{T}\int_0^T c.v.dt = \frac{p}{2\pi} V_0 C_0 \int_0^{\frac{2\pi}{p}} \sin pt \sin (pt \pm \phi) dt,$$

$$\therefore \qquad P = \frac{V_0}{\sqrt{2}} \cdot \frac{C_0}{\sqrt{2}} \cdot \cos \phi .$$

If T_1 and T_2 denote the commencement and termination of the interval during which electrical energy has been taken, then its amount is given by the equation

$$E = \int_{T_1}^{T_2} \frac{V_0}{\sqrt{2}} \cdot \frac{C_0}{\sqrt{2}} \cos \phi dt$$
$$= \int_{T_1}^{T_2} V.C \cos \phi dt,$$

where V and C are the pressure in volts and the current in amperes, as given by an alternating current voltmeter and ammeter.

An alternating current meter performs the operation expressed on the right-hand side of this equation.

Rotatory Magnetic Field.—Induction meters are used at the present day for this purpose, and are based on the rotatory magnetic field, the principles of which were first clearly enunciated by Professor Galileo Ferraris,* who communicated the results of his researches and experiments on March the 18th, 1888, in an address to the Royal Academy of Sciences of Turin. His experiments were, however, conducted in 1885.

Referring to fig. 101, if the vectors O P and O Q represent at a particular moment the instantaneous values of two forces acting at a point O in two fixed directions O X and O Y in space, then O R will represent the instantaneous value of their resultant at the same moment. The magnitude and direction of the resultant will depend on the magnitudes and directions of each of the two components, which may vary in any manner whatever, and the end of the vector O R will trace out some curve, the shape of which depends on the law of change of the two forces. When these vectors represent alternating sinusoidal stationary magnetic fields of the same frequency, their resultant will represent a magnetic field which, in general, will vary both in intensity and direction, and the end of the vector O R will move along a close curve, usually an ellipse, *i.e.* the resultant vector O R rotates round O.

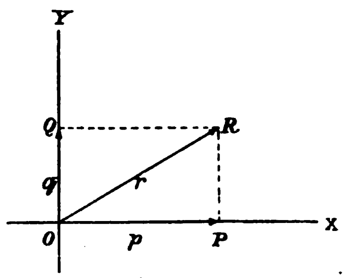

FIG. 101.

Denoting the instantaneous values of the two alternating magnetic fields by p and q, their maximum values by P and Q respectively, and if n be the frequency and ϕ the phase displacement between them, then

$$p = \mathrm{P} \sin 2\pi nt,$$
$$\text{and} \qquad q = \mathrm{Q} \sin (2\pi nt - \phi).$$

Eliminating t between these two equations gives, in general, the equation to an ellipse. It therefore follows that when two alternating magnetic fields, differing in phase, but of the same frequency, act at a point along two different directions, a rotatory magnetic field results, and in general an elliptically rotating field. If these two fields do not differ in phase, it is easy to show that a rotating magnetic field is not obtained, but a stationary alternating magnetic flux of the same character as the two components. In this case

$$p = \mathrm{P} \sin 2\pi nt.$$
$$q = \mathrm{Q} \sin 2\pi nt.$$
$$\therefore \qquad p = \frac{\mathrm{P}}{\mathrm{Q}} \cdot q \cdot$$

i.e. the locus of the resultant is a fixed straight line.

When the two component fields act at a point at right angles to one another, have the same amplitude, and differ in phase by a quarter period, the resultant magnetic field will be of constant value, and will rotate

* *Atti della R. Accademia delle Scienze di Torino*, xxiii. p. 360, 1888.

uniformly in a circle round this point. The resultant field is then called a uniformly rotating magnetic field.* This can be readily shown as follows:—

$$p = \mathrm{P} \sin 2\pi nt.$$
$$q = \mathrm{Q} \sin (2\pi nt - \phi).$$

In this case $\mathrm{P} = \mathrm{Q}$ and $\phi = \frac{\pi}{2}.$

$$\therefore \quad p = \mathrm{P} \sin 2\pi nt,$$
$$q = -\mathrm{P} \cos 2\pi nt$$
$$\therefore \quad p^2 + q^2 = \mathrm{P}^2 = r^2$$

i.e. the locus of the point R is a circle.

Rotating Vectors.—As shown by Professor Ferraris,† a stationary alternating vector, which is a sine function of the time, may be replaced by two equal and oppositely rotating vectors, each of which is half the amplitude of the fixed vector, and revolves with an angular velocity dependent on the frequency.

If O A (Fig. 102) represent the amplitude of the stationary alternating vector (maximum value of an alternating magnetic field), then O A can be replaced by the rotating vectors O B and O C, each of which is equal to one-half of O A. The two vectors rotate round O in opposite senses with the same frequency, and A O B = A O C = a represents the angular value of the phase of either rotating vector relatively to O A at the particular moment. The sum of their projections on the fixed direction O A will always give the instantaneous value of the alternating vector O A. In the position shown this value is O A′, and O A′ = O A cos a.

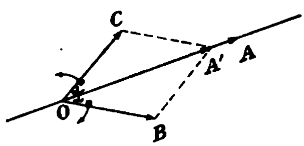

FIG. 102.

Law of the Induction Meter.—In an induction meter two stationary alternating magnetic fields are used to produce the driving torque on the revolving element, and are created by two alternating currents, differing in phase and amplitude, but of the same frequency. In a manner similar to the above, each of these fields can be decomposed into two oppositely rotating magnetic fields, giving rise to four altogether. By suitably combining the fields which rotate in the same sense, the two stationary alternating magnetic fluxes can be replaced by two oppositely rotating magnetic fields. This method ‡ can be used to demonstrate the law of the induction meter. When a rotating magnetic flux cuts a conductor at right angles, it induces in it eddy currents as it progressively revolves from point to point. If the conductor be pivoted, it will rotate under the interaction of the magnetic field and the eddies so induced, and in the same direction as the field, but with a smaller angular velocity. The torque exerted on the conductor is at any moment proportional to the product of the intensity of the magnetic flux and the strength of the eddy currents, which vary as the intensity of the magnetic flux and the angular velocity of the field relatively to the conductor. It,

* See Marcel Deprez, *Comptes Rendus*, ii. 1193, 1883.

† G. Ferraris, "Vettori Rotanti," *Mem. Reale Accad. de Sci. Torino*, serie ii., tomo xliv., Dec. 3, 1893. English Translation, "A Method for the Treatment of Rotating or Alternating Vectors," *Electrician*, xxxiii., 1894.

‡ The method used is based on the excellent article on motor meters by Dr Theodor Brüger, "Über Motorzähler," *Elektrotechnische Zeitschrift*, Heft 43, 1895.

therefore, follows that the torque varies as the square of the intensity of the magnetic field multiplied by the relative velocity of the field to the conductor.

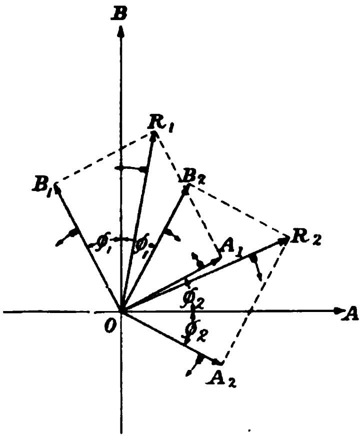

FIG. 103.

In Fig. 103, O A and O B represent the maximum values of the two alternating magnetic fluxes in an induction meter, acting at right angles to one another and to the revolving cylinder or disc. O B can be decomposed into the two equal but oppositely rotating components OB_1 and OB_2, each equal to $\frac{1}{2}$ O B, the angle BOB_1 or BOB_2 representing the angular value of the phase ϕ_1 of either component. Similarly, O A is replaced by OA_1 and OA_2, and the angle of phase is $\measuredangle AOA_1 = \measuredangle AOA_2 = \phi_2$. Combining OB_1 and OA_1, which rotate in the same direction, and also OB_2 and OA_2, the two stationary magnetic fields are replaced by the two resultant rotating fluxes OR_1 and OR_2. These two resultant fields rotate round O in opposite senses, but with the same angular velocity dependent on the frequency of the alternating current, and they also differ in magnitude.

Now $\quad OR_1^2 = OB_1^2 + B_1R_1^2 - 2OB_1.B_1R_1 \cos OB_1R_1$.
Also $\quad OR_2^2 = OB_2^2 + B_2R_2^2 - 2OB_2.B_2R_2 \cos OB_2R_2$.

Denoting the intensity of the alternating field OB by $2h$ and that of OA by 2H, then $OB_1 = OB_2 = h$, and $OA_1 = OA_2 = H$.

$$\therefore \quad OR_1^2 = h^2 + H^2 - 2h.H. \cos OB_1R_1,$$
$$OR_2^2 = h^2 + H^2 - 2h.H. \cos OB_2R_2.$$

Now O B is at right angles to O A, and it can be readily shown that $\measuredangle OB_1R_1 = \frac{\pi}{2} - (\phi_1 - \phi_2)$, and that $\measuredangle OB_2R_2 = \frac{\pi}{2} + (\phi_1 - \phi_2)$. If we denote the phase difference $(\phi_1 - \phi_2)$ of the two alternating magnetic fields by Φ, then the above equations become

$$OR_1^2 = h^2 + H^2 - 2hH \sin \Phi,$$
and $$OR_2^2 = h^2 + H^2 + 2hH \sin \Phi.$$

These two oppositely rotating magnetic fields act on the cylinder or disc, which revolves in the direction of the stronger of the two fields, the one field exerting a driving torque, and the other a resisting torque on it. If C_1 and C_2 denote the eddy currents induced in the cylinder or disc by the two fields OR_1 and OR_2 respectively, and if ω denote the angular velocity of the disc, and ω' that of each of the rotatory fields ($\omega' = 2\pi n$, where n is the frequency), then

$$C_2 \propto OR_2 (\omega' - \omega),$$
and $$C_1 \propto OR_1 (\omega' + \omega).$$

The driving torque $D_1 \propto OR_2.C_2$,

i.e. $D_1 = K_1 OR_2^2 (\omega' - \omega)$,

and the resisting torque $T_1 \propto OR_1.C_1$,

i.e. $T_1 = K_1.OR_1^2 (\omega' + \omega)$.

In addition to this retarding torque, a second one is usually added, and is produced by rotating the same disc, or another mounted on the same spindle, in the fixed field of a permanent magnet. The second retarding torque is given by the equation

$$T_2 = K.N^2.\omega,$$

where N is the strength of the permanent magnetic field, and ω is the actual angular velocity of the disc. The total brake torque is, therefore, the sum of these two; and when the condition of steady motion has been reached, the driving torque will balance the total retarding torque; then

$$D - (T_1 + T_2) = 0,$$

i.e. $$K_1.OR_2^2(\omega' - \omega) = K_1.OR_1^2 (\omega' + \omega) + K.N^2.\omega.$$
$$K_1\omega'(OR_2^2 - OR_1^2) = K_1.\omega.(OR_1^2 + OR_2^2) + K.N^2.\omega.$$

Inserting in this equation the values of OR_2 and OR_1 obtained above, then

$$K_1\omega'.4h.H. \sin \Phi = K_1\omega.2(h^2 + H^2) + K.N^2.\omega,$$

i.e. since $\omega' = 2\pi.n$,

$$K'.n.h.H \sin \Phi = 2K_1.\omega.(h^2 + H^2) + K.N^2\omega,$$

where $K' = 8\pi.K_1$.

Now $K'.n.h.H. \sin \Phi$ is the driving torque exerted on the disc of the induction meter by the two stationary alternating magnetic fluxes, $K.N^2\omega$ is the retarding torque of the permanent magnet, and $2K_1(h^2 + H^2)\omega$ is the resisting torque exerted by the driving fields themselves. This braking action of the two stationary fluxes is in general made negligibly small compared with that of the usual magnetic brake by choosing relatively weak fields and a low rotative speed of the meter disc. In this case we may put

$$2K_1(h^2 + H^2)\omega = 0,$$

and then $K'.n.h.H. \sin \Phi = K.N^2\omega$,

$\therefore$ $\omega = K''.h.H. \sin \Phi$,

where $K'' = \dfrac{K'.n}{K.N^2}$,

i.e. the speed is proportional to the product of the two stationary alternating magnetic fluxes multiplied by the sine of the angle of phase difference between them.

These two fields are produced by a pressure current and the main current in the circuit to which the meter is connected, and the pressure current is proportional to the supply voltage. The true power in the circuit is

$$P = V.C \cos \phi,$$

V and C being the voltage and current, and $\cos \phi$ the power factor.

Now $\omega = K''.h.H. \sin \Phi$

and $h \propto V$ and $H \propto C$.

$\therefore$ $\omega = K_0.V.C \sin \Phi$.

The condition for the speed of the meter disc to be proportional to the true power is, therefore,

$$\sin \Phi = \cos \phi,$$

$$i.e. \qquad \Phi = \frac{\pi}{2} \pm \phi.$$

Φ is the phase difference between the two stationary magnetic fields, and is not the same as that between the pressure and main currents producing these fields, because the time-constants of the magnetic and electrical circuits are not the same.

Hence the very important condition which must be fulfilled by an induction meter is, that the pressure and main current fluxes must have a phase displacement relatively to one another of exactly 90°, when the power factor of the circuit is unity, so that the speed of the meter disc is proportional to the true power.

Then
$$\omega = K_0 . V . C \cos \phi,$$

and
$$\int_{T_1}^{T_2} \omega dt = K_0 \int_{T_1}^{T_2} V . C \cos \phi dt.$$

If
$$\phi = 0, \quad \text{then} \quad \int_{T_1}^{T_2} \omega dt = K_0 \int_{T_1}^{T_2} V . C dt.$$

The number of revolutions exerted by the disc or cylinder of the induction meter in a given time is then proportional to the true energy consumed in the alternating current circuit in that time.

Non-inductive and Inductive Loads.—When the meter is intended for use in a circuit in which the voltage and current are always in phase with one another, *i.e.* $\cos \phi = 1$, it is not so essential for the two fluxes to differ in phase by exactly $\frac{\pi}{2}$ provided that the angle Φ be sufficiently large. The sine of a large angle does not differ appreciably from unity ($\sin 75° = 0{\cdot}96593$; $\sin 80° = 0{\cdot}98481$; $\sin 85° = 0{\cdot}99619$), so that the error will not be very great. If, however, the current lead in advance of, or lag behind, the pressure, the angle Φ must comply with the condition $\sin \Phi = \cos \phi$.

Various devices have from time to time been proposed by different investigators for creating exact quadrature between the pressure and main current fluxes in an induction meter when the current and pressure are in phase.

At the present day three distinct methods are in general use, and are explained in Chapter VIII., the induction meters described in that chapter being arranged in three corresponding classes.

Three-wire Single-phase Induction Meters.—In Chapter II. it was shown that in a three-wire direct current network the energy used is only correctly given by a single three-wire energy motor meter (assuming no errors in the meter) when the system is perfectly balanced, or when the pressures between the outer mains and the neutral wire are kept constant and equal to one another. In a similar manner it may be shown that the energy consumed in a three-wire circuit fed with single-phase alternating current is correctly measured by a three-wire energy induction meter under certain conditions only.

Let v_1 and v_2 denote the instantaneous values of the voltages between the

outer mains and the neutral wire, v the instantaneous value of the total three-wire pressure, V_1, V_2, and V being the corresponding maximum values; also let c_1 and c_2 represent the instantaneous and C_1 and C_2 the maximum currents in the two outer mains. When the system is in perfect balance and the loads contain neither self-induction nor capacity, *i.e.* the currents and voltages are all in phase,

then $$v_1 = v_2 = \tfrac{1}{2}v, \; c_1 = c_2 = c \text{ (say)};$$

and $$v_1 = V_1 \sin pt; \; v_2 = V_2 \sin pt; \; v = V \sin pt; \; c_1 = C_1 \sin pt; \; c_2 = C_2 \sin pt.$$

$$\therefore \quad V_1 = V_2 = \tfrac{1}{2}V, \text{ and } C_1 = C_2 = C \text{ (say)}.$$

The instantaneous value of the power is

$$p = c_1 v_1 + c_2 v_2,$$

or $$p = cv.$$

The mean power is

$$P = \frac{1}{T}\int_0^T c_1 v_1 dt + \frac{1}{T}\int_0^T c_2 v_2 dt,$$

or $$P = \frac{1}{T}\int_0^T cv dt$$

$$= \frac{C_1}{\sqrt{2}} \cdot \frac{V_1}{\sqrt{2}} + \frac{C_2}{\sqrt{2}} \cdot \frac{V_2}{\sqrt{2}} = \frac{V}{\sqrt{2}} \cdot \frac{C}{\sqrt{2}},$$

where $T = \dfrac{1}{n} = \dfrac{2\pi}{p}$, n being the frequency. It is obvious that in this case the meter will read correctly however its pressure circuit may be energised.

When the system is unbalanced and the pressures are not equal to one another, but the loads are purely non-inductive and have no capacity, *e.g.* consist of incandescent lamps, then the results established in Chapter II. for a direct current three-wire system hold, and the meter will read incorrectly whether its pressure circuit be energised by a current proportional to the total three-wire voltage or the pressure between either outer and the neutral main. The proof follows in exactly the same manner as for a direct current system, as the equations in this case not only hold for instantaneous values but also for effective values, there being neither self-induction nor capacity in either of the branches.

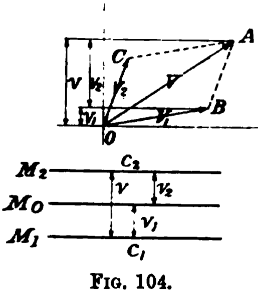

FIG. 104.

When a phase displacement exists between the pressure and the current in the two branches, whether the two sides be equally or unequally loaded, the pressures of these two sides will not be in phase with one another, and the above results are considerably modified.

Referring to Fig. 104, O A represents the maximum value V of the total three-wire pressure, O B and O C representing the maximum values V_1 and V_2 respectively of the voltages between M_1 and the neutral conductor M_0, and

M_2 and M_0. Moreover, V_1 lags behind V by some angle A O B $= a$, and V_2 is in advance of V by some angle A O C $= \beta$. Also the current in the outer main M_1 lags by some angle ϕ_1 behind the total three-wire pressure, and ϕ_2 denotes the angle of lag of the current in the second outer conductor M_2 behind V. Then quite generally the following relations hold—

$$v = V \sin pt$$
$$v_1 = V_1 \sin (pt - a) \qquad c_1 = C_1 \sin (pt - \phi_1).$$
$$v_2 = V_2 \sin (pt + \beta) \qquad c_2 = C_2 \sin (pt - \phi_2).$$

Also, if p denote the instantaneous value of the power absorbed by the whole system,

$$p = v_1 c_1 + v_2 c_2 ,$$
and
$$v = v_1 + v_2 .$$

It is not difficult to show that with the system balanced, in which case the power factor is the same for each side, and the pressures between the outers and the neutral conductor (*i.e.* maximum or root mean square values) are equal to one another, the three-wire watt-hour induction motor meter will read correctly only when its pressure circuit is energised by the total voltage of the system. It may be as well to point out here that by the power factor is meant the cosine of the angle by which the current in an outer conductor lags behind or leads in advance of the total three-wire voltage. If, on the other hand, the pressure circuit of the meter be not connected direct across the two outer mains, but between either outer and the neutral conductor, then, with the same conditions still obtaining, the meter will read high or low according as the pressure used lags behind or leads in advance of the total three-wire voltage.

Case (i). The pressure circuit of the meter is energised by a current proportional to the total three-wire voltage.

As the system is balanced, and the pressures, as measured by a voltmeter, are equal to one another, but the current is out of phase with the total voltage, then

$$\phi_1 = \phi_2 = \phi \text{ (say)} ; \quad a = \beta .$$

Also
$$V_1 = V_2 .$$

$$\therefore \qquad v = V \sin pt$$
$$v_1 = V_1 \sin (pt - a) \qquad c_1 = c_2 = C \sin (pt - \phi).$$
$$v_2 = V_1 \sin (pt + a)$$

The instantaneous value of the driving torque on the armature of the meter is proportional to d, where

$$d = \tfrac{1}{2} v (c_1 + c_2)$$
$$= v c_1 .$$

The mean value of the driving torque is proportional to D, and

$$D = \frac{1}{T} \int_0^T d \, . \, dt$$

$$= \frac{V}{\sqrt{2}} \cdot \frac{C}{\sqrt{2}} \cdot \cos \phi .$$

Thus the energy given by the meter, assuming no errors, is

$$\int_{T_1}^{T_2} \frac{V}{\sqrt{2}} \cdot \frac{V}{\sqrt{2}} \cos \phi dt .$$

Now the instantaneous value of the power absorbed is

$$\begin{aligned} p &= c_1 v_1 + c_2 v_2 \\ &= c_1(v_1 + v_2) \\ &= c_1 v \end{aligned}$$

since $\quad c_1 = c_2 \quad$ and $\quad v = v_1 + v_2 .$

The mean power is $\quad P = \frac{1}{T}\int_0^T pdt = \frac{V}{\sqrt{2}} \cdot \frac{C}{\sqrt{2}} \cos \phi .$

The true energy is, therefore,

$$\int_{T_1}^{T_2} \frac{V}{\sqrt{2}} \cdot \frac{C}{\sqrt{2}} \cos \phi dt$$

Hence in this case the meter reads correctly.

Case (ii). The pressure circuit of the meter is energised by a current proportional to the pressure between the main M_1 and the neutral wire $\left(i.e. \ \frac{V_1}{\sqrt{2}}\right)$; also V_1 lags behind V.

As in case (i.),

$$\begin{aligned} V_1 &= V_2 ; \\ v &= V \sin pt ; \\ v_1 &= V_1 \sin (pt - a) \\ v_2 &= V_1 \sin (pt + a) \\ c_1 = c_2 &= C \sin (pt - \phi). \end{aligned}$$

The instantaneous value of the driving torque is proportional to d, and

$$\begin{aligned} d &= v_1(c_1 + c_2) \\ &= 2v_1 c_1 . \\ &= 2V_1 \sin (pt - a).C \sin (pt - \phi). \end{aligned}$$

$$\therefore \qquad D = \frac{1}{T}\int_0^T d.dt$$

$$= 2\frac{V_1}{\sqrt{2}} \cdot \frac{C}{\sqrt{2}} \cos (\phi - a).$$

The meter reading is thus

$$2\int_{T_1}^{T_2} \frac{V_1}{\sqrt{2}} \cdot \frac{C}{\sqrt{2}} \cos (\phi - a) dt .$$

The true power (instantaneous value) is, as before,

$$p = c_1 v_1 + c_2 v_2$$
$$= c_1(v_1 + v_2).$$

$$\therefore \qquad p = C_1 \sin(pt - \phi)[V_1 \sin(pt - a) + V_1 \sin(pt + a)].$$

Now
$$P = \frac{1}{T}\int_0^T p.dt$$
$$= \frac{V_1}{\sqrt{2}} \cdot \frac{C}{\sqrt{2}}(\cos \overline{\phi - a} + \cos \overline{\phi + a}).$$

The true energy is

$$E = \int_{T_1}^{T_2} \frac{V_1}{\sqrt{2}} \cdot \frac{C}{\sqrt{2}} (\cos \overline{\phi - a} + \cos \overline{\phi + a}) dt,$$

i.e.
$$E = 2\int_{T_1}^{T_2} \frac{V_1}{\sqrt{2}} \cdot \frac{C}{\sqrt{2}} \cos(\phi - a) dt + \int_{T_1}^{T_2} \frac{C}{\sqrt{2}} \cdot \frac{V_1}{\sqrt{2}} (\cos \overline{\phi + a} - \cos \overline{\phi - a}) dt,$$

$$\therefore \quad E = 2\int_{T_1}^{T_2} \frac{V_1}{\sqrt{2}} \cdot \frac{C}{\sqrt{2}} \cos(\phi - a) dt - 2\int_{T_1}^{T_2} \frac{C}{\sqrt{2}} \cdot \frac{V_1}{\sqrt{2}} \cdot \sin\phi \sin a dt.$$

The meter, it will be seen, will read high although the circuits are balanced. If $\phi = a = 45°$, then the meter will measure

$$2\int_{T_1}^{T_2} \frac{V_1}{\sqrt{2}} \cdot \frac{C}{\sqrt{2}} dt,$$

whereas the true energy is

$$\int_{T_1}^{T_2} \frac{V_1}{\sqrt{2}} \cdot \frac{C}{\sqrt{2}} dt,$$

so that the meter reads 100% high.

If the meter be energised by a current proportional to the voltage between the outer main M_2 and the neutral conductor, *i.e.* by $\frac{V_2}{\sqrt{2}}$, (V_2 leads in advance of V_1) then it can be shown in the same way that the meter reads low. In this case if $\phi = a = 45°$ the meter stops, whereas the energy absorbed is

$$\int_{T_1}^{T_2} \frac{V_1}{\sqrt{2}} \cdot \frac{C}{\sqrt{2}} dt,$$

and when $\phi = a = 30°$ the meter reads $33\frac{1}{3}$% low.

When the three-wire circuit is unbalanced and the power factors of the two branches are unequal (by the power factor is meant the cosine of the angle of phase difference between the total three-wire voltage and the current in either outer), the meter will read incorrectly whether its pressure circuit be connected across the two outer conductors or across either outer and the neutral main. The equations become, however, more complicated, and no general results of any value can be deduced from them. It may be of interest to give the case when the pressure circuit of the meter is connected direct across the system.

Then $v = \mathrm{V} \sin pt\,;\; v_1 = \mathrm{V}_1 \sin (pt - \alpha)\,;\; v_2 = \mathrm{V}_2 \sin (pt + \beta)$

$c_1 = \mathrm{C}_2 \sin (pt - \phi_1)\,;\; c_2 = \mathrm{C}_2 \sin (pt - \phi_2).$

$$p = c_1 v_1 + c_2 v_2 \quad \text{and} \quad v = v_1 + v_2.$$

$$\therefore \quad p = v(c_1 + c_2) - v_2 c_1 - v_1 c_2.$$

Also $$p = v_1 c_1 + v_2 c_2.$$

$\therefore$ by addition $$2p = v(c_1 + c_2) + c_1 v_1 + c_2 v_2 - (c_1 v_2 + c_2 v_1).$$

$$\therefore \quad \mathrm{P} = \tfrac{1}{2}\left\{ \frac{\mathrm{V}}{\sqrt{2}} \cdot \frac{\mathrm{C}_1}{\sqrt{2}} \cos \phi_1 + \frac{\mathrm{C}_2}{\sqrt{2}} \cos \phi_2 \right\}$$
$$+ \tfrac{1}{2}\left\{ \frac{\mathrm{C}_1}{\sqrt{2}} \cdot \frac{\mathrm{V}_1}{\sqrt{2}} \cos (\phi_1 - \alpha) + \frac{\mathrm{C}_2}{\sqrt{2}} \cdot \frac{\mathrm{V}_2}{\sqrt{2}} \cos (\phi_2 + \beta) \right\}$$
$$- \tfrac{1}{2}\left\{ \frac{\mathrm{C}_1}{\sqrt{2}} \cdot \frac{\mathrm{V}_2}{\sqrt{2}} \cdot \cos (\phi_1 + \beta) + \frac{\mathrm{C}_2}{\sqrt{2}} \cdot \frac{\mathrm{V}_1}{\sqrt{2}} \cos (\phi_2 - \alpha) \right\}.$$

The above represents the true mean power, and taking the integral between two given times will give the true energy. It can be easily shown that the speed of the meter armature is proportional to

$$\tfrac{1}{2}\left\{ \frac{\mathrm{V}}{\sqrt{2}} \cdot \frac{\mathrm{C}_1}{\sqrt{2}} \cdot \cos \phi_1 + \frac{\mathrm{C}_2}{\sqrt{2}} \cdot \frac{\mathrm{V}}{\sqrt{2}} \cos \phi_2 \right\}$$

so that the meter will read incorrectly, and will read high or low according as the expression

$$\tfrac{1}{2}\left\{ \frac{\mathrm{C}_1}{\sqrt{2}} \cdot \frac{\mathrm{V}_1}{\sqrt{2}} \cdot \cos (\phi_1 - \alpha) + \frac{\mathrm{C}_2}{\sqrt{2}} \cdot \frac{\mathrm{V}_2}{\sqrt{2}} \cos (\phi_2 + \beta) \right\}$$
$$- \tfrac{1}{2}\left\{ \frac{\mathrm{C}_1}{\sqrt{2}} \cdot \frac{\mathrm{V}_1}{\sqrt{2}} \cdot \cos (\phi_1 + \beta) + \frac{\mathrm{C}_2}{\sqrt{2}} \cdot \frac{\mathrm{V}_1}{\sqrt{2}} \cos (\phi_2 - \alpha) \right\}$$

is $-$ or $+$. The above results are reversed with a leading current.

The energy absorbed in a single-phase alternating current three-wire system can, of course, be readily obtained by treating each half of the system as an independent two-wire circuit, in each of which a two-wire induction meter is used. When the three-wire induction meter is provided with two pressure circuits connected together in series direct across the outer mains, and the junction of these two pressure circuits is connected to the neutral wire, then, whatever the conditions that prevail, the three-wire meter will correctly measure the energy consumed in the two branches. The meter, in this case, may be regarded as a combination of two two-wire meters. It must

be borne in mind that each shunt flux should be displaced by a quarter period relatively to the main current flux with which it operates, the neutral wire being brought to the common junction of the two pressure circuits, and the load being non-inductive and containing no capacity.

Measurement of Polyphase Power.—The polyphase systems in most general use are the two-phase and three-phase with three or four wires. The measurement of power in such a system is not simple, as originally pointed out by Görges,* and only a few of the more important equations on which polyphase meters are based are given, as it is quite beyond the scope of this book to include the complete theory of alternating currents.

Equations of Power for a Three-phase Three-wire Star System.—In a three-phase three-wire system either a star (Fig. 105) or a delta (Fig. 108) connection of the three circuits is used. Referring to Fig. 105, c_1, c_2, c_3 and v_1, v_2, v_3 severally denote the instantaneous values of the currents and voltages

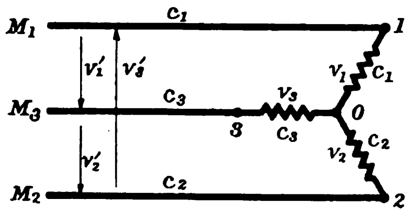

FIG. 105.

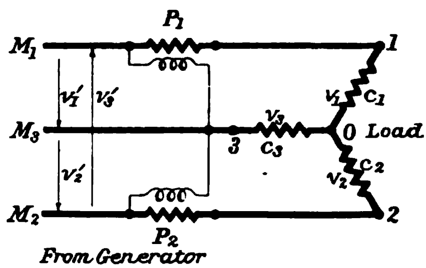

FIG. 106.

in the phase branches 01, 02, and 03. The currents in the three supply mains, M_1, M_2, M_3, for the star coupling are the same as the phase currents, but the potential differences between the mains are the differences of the phase voltages as vectors. Denoting the instantaneous values of these potential differences between the mains, as shown in the diagram by v'_1, v'_2, and v'_3, then

$$v'_1 = v_1 - v_3$$
$$v'_2 = v_3 - v_2$$
$$v'_3 = v_2 - v_1 .$$

Also $$c_1 + c_2 + c_3 = 0 .$$

The instantaneous value of the three-phase power absorbed in the star-connected circuits is

$$p = c_1 v_1 + c_2 v_2 + c_3 v_3 \qquad . \quad . \quad . \quad . \quad (13);$$

* Hans Görges, "Über Drehstrom und seine Messung," *Elektrotechnische Zeitschrift*, Heft 17, p. 213, 1891; and "On Rotary Currents and the Art of Measuring them," *Electrical Review*, vol. xxviii., 1891.

For those who wish to pursue the subject further, the following references are added:—Dr F. Zickermann, *E.T.Z.*, Heft 39, 1891; Dr H. Aron, *E.T.Z.*, Heft 15, 1892; Frölich, *E.T.Z.*, p. 574, 1893; Blondel, *Lumière Elec.*, 21st Jan. 1893; Blondel, *Proc. Elec. Congress, Chicago*, p. 112, 1893; Lunt, *Elec. World*, xxiii., 1894; Behn-Eschenburg, *E.T.Z.*, 19th March 1896; Dobrowolski and Bauch, *E.T.Z.*, 2nd April 1896; and *Elec. World*, xxiii. p. 492; Jackson, *Elec. World*, xxviii. p. 351, 1896; Prof. S. P. Thompson, *Polyphase Electric Currents*, Spon. (*E.T.Z.* = Elektrotechnische Zeitschrift.)

and making the assumption that the alternating currents and voltages all have the same periodic time T, then the mean power in this interval is

$$P = \frac{1}{T}\int_0^T c_1 v_1\,dt + \frac{1}{T}\int_0^T c_2 v_2\,dt + \frac{1}{T}\int_0^T c_3 v_3\,dt.$$

This equation shows that three wattmeters would be required, one for each of the phase circuits 01, 02, 03, and the sum of their three simultaneous readings would give the total power.

This method is impracticable on account of the general inaccessibility of the neutral point 0. Equation (13) can, however, be expressed in terms of the currents in the mains, and the potential differences between them.

$$\begin{aligned} p &= c_1 v_1 + c_2 v_2 + c_3 v_3 \\ &= c_1(v_1 - v_3) + c_2(v_2 - v_3) + v_3(c_1 + c_2 + c_3) \\ &= c_1(v_1 - v_3) + c_2(v_2 - v_3) \end{aligned}$$

since $c_1 + c_2 + c_3 = 0$.

Also $v'_1 = v_1 - v_3$ and $v'_2 = -(v_2 - v_3)$,

$$\therefore \quad p = c_1 v'_1 - c_2 v'_2,$$

and

$$P = \frac{1}{T}\int_0^T c_1 v'_1\,dt - \frac{1}{T}\int_0^T c_2 v'_2\,dt.$$

Hence the power is obtained by the use of two wattmeters P_1 and P_2 connected as in Fig. 106.

* In a three-phase system the currents and pressures are sine functions of the time, have equal periods, and are displaced relatively to one another by 120°. If the system be perfectly balanced, *i.e.* the phase branches be equally loaded, then

$$\begin{aligned} v_1 &= V_0 \sin pt, & c_1 &= C_0 \sin(pt - \phi), \\ v_2 &= V_0 \sin(pt - 120^\circ), & c_2 &= C_0 \sin(pt - 120^\circ - \phi), \\ v_3 &= V_0 \sin(pt - 240^\circ), & c_3 &= C_0 \sin(pt - 240^\circ - \phi), \end{aligned}$$

where ϕ denotes the angle of lag of the current behind the pressure. This angle will also be the same in all the three-phase circuits, 01, 02, 03, in this case, and $p = 2\pi n$, n being the frequency. Moreover, the maximum values of the pressures will be equal to one another, and the same condition will obtain for the currents.

Fig. 107 is a vector diagram of a three-phase star system, and OM_1, OM_2, OM_3 represent the maximum values of the phase voltages v_1, v_2, v_3. If the figure be rotated counter-clockwise the phase voltage V_1 will pass through its positive maximum first, taking the line OM_1 as the standard of reference, then the phase voltage V_2 and finally V_3. The P.D. at any moment between the

* Throughout this work the waves of P.D. and current, in conformity with ordinary practice, are assumed to be sine-shaped in an alternating current system, whether single-phase or polyphase. The results obtained become variously modified when this assumption no longer holds.

mains M_1 and M_3 is the difference between the voltages v_1 and v_3 (as vectors).

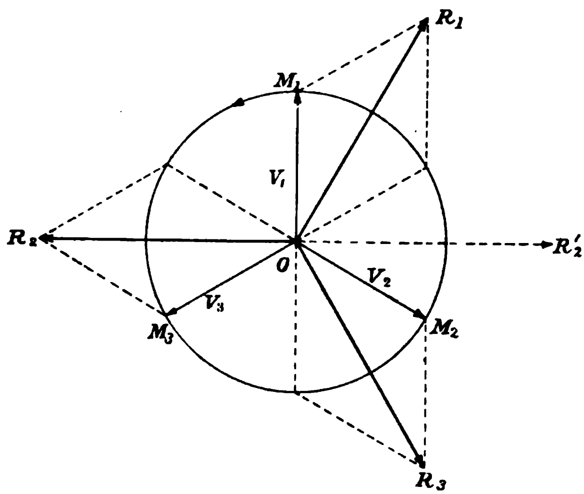

FIG. 107.

The maximum value is found by compounding V_1 with $-V_3$, and is represented by the resultant $O R_1$ in the diagram.

Since $\quad V_1 = V_2 = V_3 = V_0$ (say), $\quad \therefore \quad OR_1 = 2V_0 \cos 30°$,

i.e. $\quad OR_1 = \sqrt{3}.V_0$.

The P.D. between the mains is, therefore, $\sqrt{3}$ times the phase voltage V_1 and lags 30° behind it. In the same manner $O R_2$ is the maximum value of the P.D. between M_3 and M_2 and lags 270° behind V_1, and $O R_3$ is the P.D. (maximum value) between M_2 and M_1 and lags behind V_1 by 150°; $O R'_2 = -O R_2$ and lags 90° behind V_1.

The instantaneous values of the pressures across the mains are thus—

$$v'_1 = v_1 - v_3 = \sqrt{3}.V_0 \sin(pt - 30°)$$
$$v'_2 = v_3 - v_2 = \sqrt{3}.V_0 \sin(pt - 270°)$$
$$v'_3 = v_2 - v_1 = \sqrt{3}.V_0 \sin(pt - 150°).$$

Also $$-v'_2 = v_2 - v_3 = \sqrt{3}.V_0 \sin(pt - 90°).$$

The mean power is

$$P = \frac{1}{T}\int_0^T c_1.v'_1\,dt - \frac{1}{T}\int_0^T c_2.v'_2\,dt$$

$$= \frac{1}{T}\int_0^T C_0 \sin(pt - \phi)\,\sqrt{3}.V_0 \sin(pt - 30°)dt \qquad [+$$

$$+\frac{1}{T}\int_0^T C_0 \sin(pt-120°-\phi)\,\sqrt{3}.V_0 \sin(pt-90°)dt.$$

And $$T=\frac{1}{n}=\frac{2\pi}{p}.$$

$$\therefore \quad P=\frac{\sqrt{3}.V_0C_0}{2\pi}\int_0^{\frac{2\pi}{p}} \sin(pt-\phi).\sin(pt-30°)dpt$$

$$+\frac{\sqrt{3}.V_0C_0}{2\pi}\int_0^{\frac{2\pi}{p}} \sin(pt-120°-\phi)\sin(pt-90°)dpt.$$

$$\therefore \quad P=\frac{\sqrt{3}}{2\pi}.\frac{V_0C_0}{2}\left\{\int_0^{\frac{2\pi}{p}}\cos(\phi-30°)dpt-\int_0^{\frac{2\pi}{p}}\cos(2pt-\phi-30°)dpt\right\}$$

$$+\frac{\sqrt{3}}{2\pi}.\frac{V_0C_0}{2}\left\{\int_0^{\frac{2\pi}{p}}\cos(\phi+30°)dpt-\int_0^{\frac{2\pi}{p}}\cos(2pt-210°+\phi)dpt\right\}$$

$$\therefore \quad P=\sqrt{3}\cdot\frac{V_0C_0}{2}\cos(\phi-30°)+\sqrt{3}\cdot\frac{V_0C_0}{2}\cdot\cos(\phi+30°).$$

i.e. $$P=\sqrt{3}.V.C\cos(\phi-30°)+\sqrt{3}.V.C.\cos(\phi+30°) \quad . \quad . \quad (14),$$

where V and C are the root mean square values of the phase voltage and the phase or main current. When the system is balanced the one wattmeter P_1 (Fig. 106) reads $\sqrt{3}.V.C.\cos(\phi-30°)$, and the other wattmeter P_2 reads $\sqrt{3}.V.C.\cos(\phi+30°)$, the sum of these two readings giving the total three-phase power, viz. $3.V.C.\cos\phi$.

The equation

$$P=\frac{1}{T}\int_0^T c_1.v_1'dt-\frac{1}{T}\int_0^T c_2.v'_2dt,$$

or $$P=\frac{1}{T}\int_0^T c_1(v_1-v_3)dt-\frac{1}{T}\int_0^T c_2(v_3-v_2)dt,$$

holds whatever the manner in which the phase branches may be loaded.

When they are unbalanced, then

$$v_1=V_1\sin pt \qquad c_1=C_1\sin(pt-\phi_1)$$
$$v_2=V_2\sin(pt-\alpha) \qquad c_2=C_2\sin(pt-\alpha-\phi_2)$$
$$v_3=V_3\sin(pt-\beta) \qquad c_3=C_3\sin(pt-\beta-\phi_3).$$

In this case the total three-phase power is

$$V'_1C'_1 \cos\phi_1 + V'_2C'_2 \cos\phi_2 + V'_3C'_3 \cos\phi_3,$$

where V'_1, V'_2, V'_3 and C'_1, C'_2, C'_3 are the root mean square values of the phase pressures and currents, and $\cos\phi_1$, $\cos\phi_2$, $\cos\phi_3$, are the power factors of the three branches. The two wattmeter readings will give the true power in this case also. This may be shown as follows:—

$$P = \frac{1}{T}\int_0^T c_1(v_1 - v_3)dt - \frac{1}{T}\int_0^T c_2(v_3 - v_2)dt.$$

$$\therefore \quad P = \frac{1}{T}\int_0^T C_1.V_1 \sin(pt - \phi_1)\sin pt\, dt$$

$$- \frac{1}{T}\int_0^T C_1.V_3 \sin(pt - \beta)\sin(pt - \phi_1)dt$$

$$- \frac{1}{T}\int_0^T C_2.V_3(pt - a - \phi_2)\sin(pt - \beta)dt$$

$$+ \frac{1}{T}\int_0^T C_2.V_2 \sin(pt - a)\sin(pt - a - \phi_2)dt.$$

i.e. $$P = \frac{C_1V_1}{2}\cos\phi_1 + \frac{C_2V_2}{2}\cos\phi_2 - \frac{V_3}{2}\left\{C_1\cos(\phi_1 - \beta) + C_2\cos(a + \phi_2 - \beta)\right\} \quad . \quad . \quad . \quad (i).$$

Now $\quad c_1 + c_2 + c_3 = 0$

$$\therefore \quad C_1\sin(pt - \phi_1) + C_2\sin(pt - a - \phi_2) + C_3\sin(pt - \beta - \phi_3) = 0$$

i.e. $$\{C_1\cos\phi_1 + C_2\cos(a + \phi_2) + C_3\cos(\beta + \phi_3)\}\sin pt$$
$$- \{C_1\sin\phi_1 + C_2\sin(a + \phi_2) + C_3\sin(\beta + \phi_3)\}\cos pt = 0.$$

It, therefore, follows that

$$C_1\cos\phi_1 + C_2\cos(a + \phi_2) + C_3\cos(\beta + \phi_3) = 0 \quad . \quad . \quad (ii)$$

and $$C_1\sin\phi_1 + C_2\sin(a + \phi_2) + C_3\sin(\beta + \phi_3) = 0 \quad . \quad . \quad (iii).$$

Multiplying the left-hand terms of equation (ii) by $\cos\beta$ and those of equation (iii) by $\sin\beta$, we obtain by addition

$$C_1\cos(\phi_1 - \beta) + C_2\cos(a + \phi_2 - \beta) + C_3\cos\phi_3 = 0,$$

i.e. $$C_1\cos(\phi_1 - \beta) + C_2\cos(a + \phi_2 - \beta) = -C_3\cos\phi_3.$$

Inserting this result in equation (i), it follows that

$$P = \frac{C_1V_1}{2}\cos\phi_1 + \frac{C_2V_2}{2}\cos\phi_2 + \frac{C_3V_3}{2}\cos\phi_3,$$

i.e. $$P = C'_1.V'_1\cos\phi_1 + C'_2.V'_2\cos\phi_2 + C'_3.V'_3\cos\phi_3.$$

Hence, however unbalanced the system may be, two wattmeters, as shown in Fig. 106, will measure the true power, and consequently two watt-hour induction meters connected in the same manner will give the energy taken in a given time.

Transformations of the fundamental equation of the instantaneous power absorbed in a three-phase star system (Fig. 105) may be obtained as follows :—

$$p = c_1v_1 + c_2v_2 + c_3v_3 \quad . \quad . \quad . \quad . \quad . \quad (13),$$
$$c_1 + c_2 + c_3 = 0$$
$$v'_1 = v_1 - v_3$$
$$v'_2 = v_3 - v_2$$
$$v'_3 = v_2 - v_1$$

Inserting successively in equation (13) $c_1 = -c_2 - c_3$, $c_2 = -c_1 - c_3$, $c_3 = -c_1 - c_2$, and using the above equations between the voltages, it can be easily shown that

$$p = c_2.v'_3 - c_3.v'_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (15),$$
$$p = c_3.v'_2 - c_1.v'_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad (16),$$
$$p = c_1.v'_1 - c_2.v'_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (17).$$

Adding equations (15) and (16),

$$2p = v'_3(c_2 - c_1) + c_3(v'_2 - v'_1) \quad . \quad . \quad . \quad . \quad . \quad (18).$$

From equations (15), (16), and (17) by addition

$$3p = c_1(v'_1 - v'_3) + c_2(v'_3 - v'_2) + c_3(v'_2 - v'_1) \quad . \quad . \quad . \quad (19),$$

or $$3p = v'_1(c_1 - c_3) + v'_2(c_3 - c_2) + v'_3(c_2 - c_1) \quad . \quad . \quad . \quad (20).$$

If the system be perfectly balanced, *i.e.* if

$$c_1(v'_1 - v'_3) = c_2(v'_3 - v'_2) = c_3(v'_2 - v'_1),$$

$$\left.\begin{array}{ll} \text{then} & p = c_1(v'_1 - v'_3), \\ \text{or} & p = c_2(v'_3 - v'_2), \\ \text{or} & p = c_3(v'_2 - v'_1), \end{array}\right\} \quad . \quad . \quad . \quad . \quad . \quad (21).$$

Equations of Power for a Three-phase Three-wire Delta System.—In the delta coupling of the three-phase circuits (Fig. 108) the voltages between

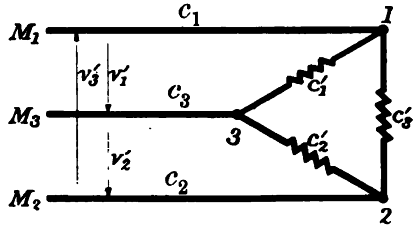

FIG. 108.

the mains are the same as those across the sides of the triangle, but the phase currents differ from the currents in the mains M_1, M_2, and M_3.

The currents in the legs of the triangle are denoted by c'_1, c'_2, c'_3, those in the mains by c_1, c_2, c_3, and the pressures by v'_1, v'_2, v'_3, all being instantaneous values. It will be readily seen that the following relations hold :—

$$c_1 + c'_3 - c'_1 = 0 \quad \therefore \quad c_1 = c'_1 - c'_3,$$
$$c_2 + c'_2 - c'_3 = 0 \quad \therefore \quad c_2 = c'_3 - c'_2,$$
$$c_3 + c'_1 - c'_2 = 0 \quad \therefore \quad c_3 = c'_2 - c'_1.$$

Also $$v'_1 + v'_2 + v'_3 = 0.$$

The instantaneous value of the power is

$$p = c'_1.v'_1 + c'_2.v'_2 + c'_3.v'_3 \quad . \quad . \quad . \quad . \quad (22).$$

In the majority of cases it would be impossible to measure the currents in the legs of the triangle; and it is, therefore, necessary to transform equation (22) so that it contains the currents in the supply mains and the pressures between them. From (22) it follows that

$$p = v'_1(c'_1 - c'_3) + v'_2(c'_2 - c'_3) + c'_3(v'_1 + v'_2 + v'_3)$$
$$= v'_1(c'_1 - c'_3) + v'_2(c'_2 - c'_3)$$

Since $$v'_1 + v'_2 + v'_3 = 0.$$

Also $$c_1 = c'_1 - c'_3 \quad \text{and} \quad c_2 = c'_3 - c'_2.$$

$$\therefore \quad p = v'_1 c_1 - v'_2 c_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23).$$

Hence $$P = \frac{1}{T}\int_0^T c_1 v'_1 dt - \frac{1}{T}\int_0^T c_2 v'_2 dt.$$

It thus follows that, as in the former case with the star connection, two watt-meters are necessary.

Assuming an equally loaded system, then

$$\begin{aligned} v'_1 &= V'_0 \sin pt & c'_1 &= C_0 \sin (pt - \phi) \\ v'_2 &= V'_0 \sin (pt - 120°) & c'_2 &= C_0 \sin (pt - 120° - \phi) \\ v'_3 &= V'_3 \sin (pt - 240°) & c'_3 &= C_0 \sin (pt - 240° - \phi). \end{aligned}$$

Now $$c_1 = c'_1 - c'_3 = C_0 \sin (pt - \phi) - C_0 \sin (pt - 240° - \phi)$$
$$= \sqrt{3}.C_0 \sin (pt - \phi - 30°).$$

Also $$c_2 = c'_3 - c'_2 = C_0 \sin (pt - 240° - \phi) - C_0 \sin (pt - 120° - \phi)$$
$$= - \sqrt{3}.C_0 \sin \left(pt - \phi - \frac{\pi}{2}\right).$$

$$\therefore \quad P = \frac{1}{T}\int_0^T \sqrt{3}.C_0 \sin (pt - \phi - 30°).V'_0 \sin pt.dt$$

$$+ \frac{1}{T}\int_0^T \sqrt{3}.C_0 \sin \left(pt - \phi - \frac{\pi}{2}\right).V'_0 \sin (pt - 120°)dt.$$

The equation for the mean power, as in the former case, reduces to

$$P = \sqrt{3}.V.C. \cos (\phi + 30°) + \sqrt{3}.V.C. \cos (\phi - 30°),$$

V being the root mean square value of the P.D. between the mains and C the root mean square value of the current in one of the legs of the triangle.

Two-Wattmeter Method of Measuring Polyphase Power.—The power absorbed in a three-phase three-wire system is thus obtained by taking the simultaneous readings of two wattmeters P_1 and P_2, connected as in Fig. (109), whether the circuits be star or delta coupled, and whatever the distribution of the loads. Two watt-hour induction meters will, therefore, in the same way, measure the total energy supplied to a three-phase three-wire network when connected to the system on this method, known as the two-wattmeter method of measuring power.

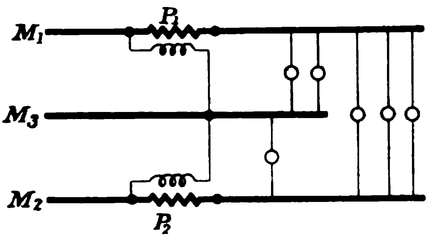

FIG. 109.

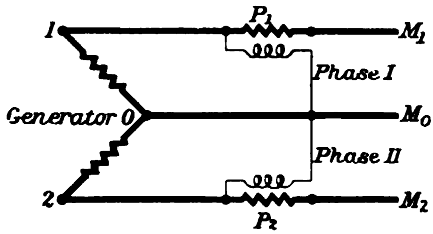

FIG. 110.

Two-phase System.—In a two-phase three- or four-wire system the power is also measured by means of two wattmeters, and two watt-hour induction meters will give the total two-phase energy consumption. In general the two phases are kept distinct from one another, and the system consists simply of two single-phase alternating current circuits, differing in phase by a quarter period.

In a two-phase three-wire system (Fig. 110) the one conductor M_0 acts as a common return to the other two. The instantaneous value of the current flowing in it is the sum of the instantaneous values of the two currents in M_1 and M_2. When the system is balanced and there is no displacement between the currents and pressures, if C denote the R.M.S. value of the current in M_1 or M_2, then the current in M_0 is $\sqrt{2}.C$, and the pressure across M_1 and M_2 is $\sqrt{2}.V$, where V is the R.M.S. value of the P.D. between M_1 and M_0, or M_0 and M_2.

Referring again to the delta coupling (Fig. 108), the instantaneous value of the power may be variously expressed as follows:—

$$p = c'_1.v'_1 + c'_2.v'_2 + c'_3.v'_3 \quad . \quad . \quad . \quad . \quad . \quad (22).$$

Also $\quad v'_1 + v'_2 + v'_3 = 0$

and $\quad c_1 + c'_3 - c'_1 = 0$

$$c_2 + c'_2 - c'_3 = 0$$

$$c_3 + c'_1 - c'_2 = 0 .$$

Inserting successively in equation (22) $v'_3 = -v'_1 - v'_2$, $v'_2 = -v'_1 - v'_3$ and $v'_1 = -v'_2 - v'_3$, and using the relations between the currents in the supply mains and those in the legs of the triangle, then

$$p = v'_1 c_1 - v'_2.c_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (23),$$

$$p = v'_3 c_2 - v'_1 c_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad (24),$$

$$p = v'_2 c_3 - v'_3 c_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (25).$$

These equations were first obtained by Dr Aron,* and used in the construction of polyphase meters.

From equations (24) and (25) by addition,

$$2p = v'_3(c_2 - c_1) + c_3(v'_2 - v'_1), \quad . \quad . \quad . \quad . \quad (26).$$

Similarly

$$2p = v'_2(c_3 - c_2) + c_1(v'_1 - v'_3), \quad . \quad . \quad . \quad . \quad (26a),$$

$$2p = v'_1(c_1 - c_3) + c_2(v'_3 - v'_2), \quad . \quad . \quad . \quad . \quad (26b).$$

Adding equations (23), (24), and (25) together, then

$$3p = v'_1(c_1 - c_3) + v'_2(c_3 - c_2) + v'_3(c_2 - c_1), \quad . \quad . \quad (27),$$

or

$$3p = c_1(v'_1 - v'_3) + c_2(v'_3 - v'_2) + c_3(v'_2 - v'_1), \quad . \quad . \quad (28).$$

(27) and (28) are the oldest equations for the measurement of power in a three-phase system, and were originally established by Görges.

If the system be perfectly balanced, then

$$c_1(v'_1 - v'_3) = c_2(v'_3 - v'_2) = c_3(v'_2 - v'_1),$$

and equation (28) reduces to

$$p = c_1(v'_1 - v'_3) = c_2(v'_3 - v'_2) = c_3(v'_2 - v'_1), \quad . \quad . \quad (29).$$

From equation (29) it follows that the three-phase power in a perfectly balanced network can be measured by means of one wattmeter, the main coil of which is placed in one of the supply mains, the one end of the shunt coil of the wattmeter being permanently connected to that main, while the other

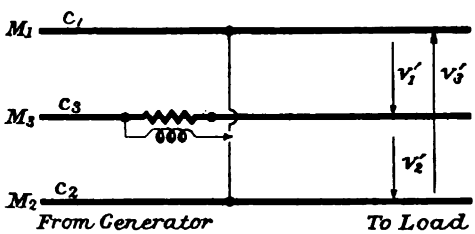

FIG. 111.

end is connected to the arm of a two-way switch, by means of which it can be alternately joined to the other two mains. This will be understood by reference to Fig. 111.

Equations of Power for a Three-phase System with Four Conductors.— In a three-phase system with four conductors,† the equations for the power absorbed become, in general, modified, owing to the current in the neutral conductor not being zero.

A three-phase four-wire system combined with star and delta connections

* Dr Aron, *Elektrotechnische Zeitschrift*, 1892, Heft 15. English Patent No. 21354, 1891.

† The equations for a three-phase four-wire system were first given by Dr H. Aron, Elektricitätszähler für Dreiphasenstrom mit vier Leitungen, *Elektrotechnische Zeitschrift*, Heft 10, 1901. Dr Aron's British Patent 21355, 1899. Also Polyphase Meters, *Elec. Review*, vol. lvi. p. 384, 1905. Further, see Dr G. Stern, *Elektrotechnische Zeitschrift*, Heft 12, 1901.

is illustrated diagrammatically in Fig. 112, and the letters have the following meanings :—

c_1, c_2, c_3, and c_0 denote the instantaneous values of the currents in the three supply mains M_1, M_2, M_3 and the fourth conductor M_0 respectively ;

c'_1, c'_2, c'_3 are the instantaneous values of the currents in the star branches.			
v_1, v_2, v_3	,,	,,	pressures ,,
c''_1, c''_2, c''_3	,,	,,	currents in the legs of the triangle.
v'_1, v'_2, v'_3	,,	,,	pressures across the corners of the triangle.

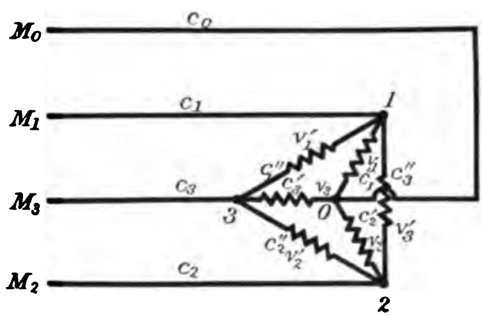

Fig. 112.

The instantaneous value of the power absorbed in the combined mesh is

$$p = c''_1 v'_1 + c''_2 . v'_2 + c''_3 . v'_3 + c'_1 . v_1 + c'_2 . v_2 + c'_3 . v_3 , \quad . \quad . \quad (30).$$

The following relations also hold :—

$$v'_1 = v_1 - v_3 ; \qquad v'_2 = v_3 - v_2 ; \qquad v'_3 = v_2 - v_1 ;$$

$$c_1 + c_2 + c_3 + c_0 = 0 ;$$

$$c_1 = c'_1 + c''_1 - c''_3 ;$$

$$c_2 = c'_2 + c''_3 - c''_2 ;$$

$$c_3 = c'_3 + c''_2 - c''_1 .$$

Substituting in equation (30) the values of v'_1, v'_2, v'_3, we obtain

$$p = c''_1(v_1 - v_3) + c''_2(v_3 - v_2) + c''_3(v_2 - v_1) + c'_1 v_1 + c'_2 . v_2 + c'_3 . v_3 ,$$

which may be written in the form

$$p = v_1(c'_1 + c''_1 - c''_3) + v_2 .(c'_2 + c''_3 - c''_2) + v_3(c'_3 + c''_2 - c''_1),$$

and giving the expressions in the brackets their values in terms of the currents in the mains, then

$$p = v_1 . c_1 + v_2 . c_2 + v_3 . c_3 , \quad . \quad . \quad . \quad . \quad (31).$$

The total power absorbed is obtained by means of three wattmeters having their current coils connected in the three supply mains M_1, M_2, M_3, and their volt coils connected between these mains and the neutral conductor M_0.

Now $\qquad v_1 + v_2 + v_3 = 0 .$

Hence, by inserting in equation (31), $v_3 = -(v_1 + v_2)$,

$$p = v_1(c_1 - c_3) + v_2(c_2 - c_3) \quad . \quad . \quad . \quad . \quad (32).$$

Similarly, by substituting for v_2 and v_1 in succession, we obtain

$$p = v_1(c_1 - c_2) + v_3(c_3 - c_2), \quad . \quad . \quad . \quad . \quad (33),$$

and $$p = v_2(c_2 - c_1) + v_3(c_3 - c_1), \quad . \quad . \quad . \quad . \quad (34).$$

Equation (32) may be written in the form

$$p = v_1 c_1 + v_2 c_2 - c_3(v_1 + v_2).$$

But $$v_1 = v'_1 + v_3,$$
$$v_2 = v_3 - v'_2,$$

and $$v_1 + v_2 = -v_3$$

$\therefore$ $$p = v'_1.c_1 + v_3(c_1 + c_2 + c_3) - c_2.v'_2,$$

and $$c_1 + c_2 + c_3 = -c_0.$$

$\therefore$ $$p = c_1 v'_1 - c_0.v_3 - c_2 v'_2.$$

Further $$v_1 + v_2 + v_3 = v'_1 + v_3 + v_3 - v'_2 + v_3$$
$$= 3v_3 + v'_1 - v'_2.$$

and $$v_1 + v_2 + v_3 = 0.$$

$$\therefore \quad v_3 = \frac{v'_2 - v'_1}{3}.$$

Substituting for v_3,

$$p = v'_1\left(c_1 + \frac{c_0}{3}\right) - v'_2\left(c_2 + \frac{c_0}{3}\right) \quad . \quad . \quad . \quad . \quad (35).$$

From equation (33) we obtain

$$p = c_1 v_1 + c_3 v_3 - c_2(v_1 + v_3).$$

But $$v_1 = v_2 - v'_3,$$
$$v_3 = v_2 + v'_2,$$
$$v_2 = v_2.$$

$\therefore$ $$v_1 + v_2 + v_3 = 0 = 3v_2 + v'_2 - v'_3,$$

$\therefore$ $$v_2 = \frac{v'_3 - v'_2}{3}.$$

$\therefore$ $$p = c_1(v_2 - v'_3) + c_3(v_2 + v'_2) + v_2 c_2,$$
$$= c_3.v'_2 - c_1 v'_3 + v_2(c_1 + c_2 + c_3),$$
$$= c_3.v'_2 - c_1.v'_3 - c_0.v_2.$$

or $$p = v'_2\left(c_3 + \frac{c_0}{3}\right) - v'_3\left(c_1 + \frac{c_0}{3}\right) \quad . \quad . \quad . \quad . \quad (36).$$

In an analogous manner it may be shown that

$$v_1 = \frac{v'_1 - v'_3}{3},$$

and that equation (34) becomes

$$p = c_2.v'_3 - c_3.v'_1 - c_0.v_1,$$

or
$$p = v'_3\left(c_2 + \frac{c_0}{3}\right) - v'_1\left(c_3 + \frac{c_0}{3}\right) \quad . \quad . \quad . \quad (37).$$

Adding equations (36) and (37),

$$2p = v'_3(c_2 - c_1) + \left(c_3 + \frac{c_0}{3}\right)(v'_2 - v'_1) \quad . \quad . \quad (38).$$

From equations (35), (36), and (37)

$$3p = v'_3(c_2 - c_1) + v'_2(c_3 - c_2) + v'_1(c_1 - c_3) \quad . \quad . \quad (39).$$

Comparison of Equations for Three-phase Systems with Three and with Four Conductors.—It will be seen, on comparing the equations for the power absorbed in a three-phase three-wire system (delta or star) with the corresponding equations for a three-phase network with four wires (star or mixed connections), that a three-phase meter designed for use on a system with three conductors will, in general, not be suitable for the measurement of the energy absorbed when a fourth conductor from the neutral point of the star is used. To emphasise this point these equations are again given below :—

$$\left.\begin{aligned} p &= c_1.v'_1 - c_2.v'_2 \\ 2p &= v'_3(c_2 - c_1) + c_3(v'_2 - v'_1) \\ 3p &= v'_1(c_1 - c_3) + v'_2(c_3 - c_2) + v'_3(c_2 - c_1) \end{aligned}\right\} \text{Three-phase System with Three Wires.}$$

$$\left.\begin{aligned} p &= v'_1\left(c_1 + \frac{c_0}{3}\right) - v'_2\left(c_2 + \frac{c_0}{3}\right) \\ 2p &= v'_3(c_2 - c_1) + \left(c_3 + \frac{c_0}{3}\right)(v'_2 - v'_1) \\ 3p &= v'_1(c_1 - c_3) + v'_2(c_3 - c_2) + v'_3(c_2 - c_1) \end{aligned}\right\} \text{Three-phase System with Four Wires.}$$

In the above, c_1, c_2, c_3 are the instantaneous values of the currents in the supply mains, v'_1, v'_2, v'_3 the instantaneous values of the pressures between these mains, and c_0 is the instantaneous value of the current in the fourth or neutral conductor. It also follows from the above equations that a meter designed on the principle expressed in the equation

$$3p = v'_1(c_1 - c_3) + v'_2(c_3 - c_2) + v'_3(c_2 - c_1)$$

will be applicable to a three-phase system with three or four conductors, the reason being, that, as only the differences between the main currents are involved, the current in the neutral wire becomes obliterated from the equation. Further, from any given equation for a three-phase three-wire system, the corresponding equation for a system with four wires is readily obtained by adding $\frac{c_0}{3}$ to each term representing a current in one of the three supply mains of the four-wire system.

The currents c_1, c_2, c_3 in the mains of the three-phase three-wire network are, of course, not the same as the currents c_1, c_2, c_3 when four wires are used.

CHAPTER VIII.

SINGLE-PHASE INDUCTION METERS.

General Description—Phase Difference between Pressure and Main Current Fields—Methods of Phase Compensation—Effect of Over-Compensation and Under-Compensation—Electrical Company's Induction Meter—Hartmann & Braun Induction Meter—Siemens-Schuckert Induction Meters—Deutsch-Russische Induction Meter—Induction Meter of Mix & Genest—Hookham Induction Meter—Westinghouse Induction Meter—Aron Induction Meter—Bat Induction Meter—Brush-Gutmann Induction Meter—Ferranti-Hamilton Induction Meter—Fort Wayne Induction Meters—High Torque Induction Meter of the General Electric Company, U.S.A.—Scheeffer Induction Meter—Stanley Induction Meter—A.C.T. Induction Meter—Induction Meters of the Compagnie Anonyme Continentale, Paris—Eclipse Induction Meters—Meters with Current and Pressure Transformers.

General Description.—The electrical energy consumed in a given time in an alternating current circuit is, at the present day, almost exclusively measured by means of meters of the induction type, in which the inductive effect of several currents differing in phase is utilised. A very simple construction is obtained by the use of this principle, giving a small energy loss and a light revolving element, with the total elimination of brush friction and the troubles inherent to commutators and brushes.

Commutator motor meters, without iron in either the armature or field system, such as have been included in Chapter IV., were originally used for this purpose, but have been completely superseded by the induction meter on account of its manifold advantages.

In general, alternating current induction meters are designed on the principle of Ferraris, in which non-magnetic solids, revolving discs or cylinders of copper or aluminium, are acted upon by rotary or progressively shifting magnetic fields, arranged symmetrically or asymmetrically to the axis.

In the meters based on the rotary field of Ferraris, two stationary solenoids or electro-magnets are used, usually situated together on one side of the axis of the revolving element. The one coil is traversed by the main current in the circuit and the other by a pressure current. The two fields of these coils are displaced in phase and usually cross one another, producing rotation of the movable conductor. The motor in an induction meter is really a split-phase motor, the rotor of which in general rotates in a two-phase rotary field. The one phase of this field is produced by the current taken by the installation, the other by means of a branch circuit in parallel with the supply mains.

An induction motor meter has essentially three main parts—the motor proper, the brake system, and the integrating mechanism.

The revolving element is either a light disc or bell mounted on a short vertical spindle, which also carries a driving worm. The stator of the motor consists of a shunt and series electro-magnetic system, which produces a driving torque on the revolving element proportional to the product of the two fields multiplied by the sine of the angle of phase displacement between them. The work done by the motor consists in driving the integrating mechanism and the brake system, which latter is the ordinary Foucault brake.

In general, the same armature disc is used as the brake disc and revolves between the jaws of a permanent magnet, which induces in it the eddy currents producing the retarding torque proportional to the speed.

The revolutions of the meter spindle are transferred by means of the worm to an integrating mechanism, which is an ordinary train of wheels actuating the hands of a dial counter or number discs, the figures of which appear in line in slots in the dial face and usually spring into position. In either case the figures of the dials indicate directly, without the use of a multiplier or constant, the energy consumption in Board of Trade or other convenient units.

Phase Difference between Pressure and Main Current Fields.—The driving torque, as already stated, is proportional to the product of the two fields acting on the disc, multiplied by the sine of the angle of phase difference. The one field is produced by the main current winding and the other by the pressure winding of the meter, so that they are respectively proportional to the main current in and the pressure of the circuit.

The angle of phase difference varies in different meters from about 70 to 80 or 85 degrees, and the sine of an angle of 85 degrees does not differ appreciably from unity. The driving torque is then proportional, very approximately, to the product of the current and voltage, or the power delivered to the circuit, but only when the current and the voltage are in phase with one another.

For purely non-inductive loads, such as incandescent lamps, it is not essential that the meter should be artificially compensated, so that the angle of lag between the shunt flux and the main current flux, when the current and voltage are in phase, should be exactly 90 degrees. When the meter is intended for use on circuits in which the current is out of phase with the impressed E.M.F., it is absolutely necessary, for the meter to register correctly, that the angle of phase difference between its two fields is artificially increased until it is a right angle. In this case if ϕ denote the angle by which the current either leads in advance of or lags behind the pressure across the supply mains, the angle of phase displacement between the shunt and series fluxes will be $90° \pm \phi$, and the sine of this angle will be equal to $\cos \phi$, which is the power factor of the circuit. The driving torque under these conditions is proportional to the product of the current and pressure multiplied by the power factor, that is, the true power delivered to the circuit, and therefore the revolutions of the meter disc executed in a given time will be proportional to the true energy consumption in that interval.

Methods of Phase Compensation.—Various methods are in vogue by means of which the meter is compensated to produce the desired phase relationship. Induction meters may be divided into three classes according to the method used in attaining this result, and this classification has been adhered to in the descriptions of the meters included in this chapter.

The first method consists in the employment of an impedance coil and a non-inductive resistance in combination with the pressure winding of the meter. In this way the shunt current, already lagging by a considerable angle behind the pressure, gives rise to two components, of which the one, traversing the shunt coils and producing the shunt flux, is caused to lag still further behind the total shunt current, and the shunt flux, by suitably adjusting the different circuits, will be displaced by exactly 90 degrees from the impressed E.M.F.

In the second method, which is analogous to the first in so far as it operates on the pressure circuit only, the phase compensation is obtained by the use of a short-circuited secondary winding which gives rise to a magnetic field displaced by more than 90 degrees from the shunt current. These two fields combine to a resultant shunt flux, which, by suitably designing the shunt electro-magnet regulating the impedance coil, if any, and adjusting the conductivity of the secondary winding, will be at right angles to the pressure, or to the main current flux when the current is in phase with the E.M.F.

The third method differs materially from the other two, in that it affects the main current flux. As large an angle of phase difference between the shunt and the pressure is obtained either with or without an impedance coil, and the main current winding is composed of two portions, of which the one is highly inductive and the other has very little self-induction. By this means a resultant series flux is produced, leading by an angle in advance of the pressure. By proper adjustment of the relative inductance of the two main current circuits of the meter, this angle of lead will be the complement of the angle of lag of the shunt flux behind the pressure when the current and E.M.F. are in phase. When this condition is fulfilled the meter will register correctly on inductive loads.

Vector diagrams illustrating these methods are given in connection with the description of the representative types of the meters belonging to these three classes. In each case the magnetic flux produced by a current flowing in the shunt or series winding is shown in phase with the current. This is not strictly correct, as the current will, in general, lead in advance of the flux to which it gives rise, because the time constants of the electrical and magnetic circuits are never quite the same. This very slight difference does not in any way affect the result, and has not been taken into account, for the sake of clearness in the diagrams.

Effect of Over-Compensation and Under-Compensation.—The true power in an alternating current circuit is given by the equation $P = C.V. \cos \phi$, where C denotes the current, V is the voltage, and $\cos \phi$ is the power factor. Whether the condition of exact quadrature between the series and shunt fields, when the load is non-inductive, be fulfilled, or not, the torque exerted on the disc is

$$D = K.F_s.F_r \sin \Phi .$$

F_s and F_r denote respectively the resultant shunt and series fluxes, Φ is the phase displacement between them, and K is a constant.

When the meter is properly adjusted, $\Phi = \frac{\pi}{2} \pm \phi$, ϕ being the angle by which the current leads in advance of or lags behind the pressure, and it then registers correctly on loads of any power factor. If an induction meter be over-compensated, *i.e.* when the power factor is unity, if the angle

between the main current and shunt fluxes exceed $\frac{\pi}{2}$ by some small angle a, then the meter will read high when the current is a lagging current, and when a equals the angle of lag the reading will be a maximum, the power, as registered by the speed of the meter, corresponding to the power when the load is non-inductive.

$$\text{Now} \qquad D = K.F_s.F_r \sin \Phi$$

$$\text{but} \qquad F_s \propto V \quad \text{and} \quad F_r \propto C$$

$$\text{also} \qquad \Phi = \left(\frac{\pi}{2} + a - \phi\right)$$

$$\therefore \quad D = K'.V.C \sin\left(\frac{\pi}{2} - \overline{\phi - a}\right)$$

$$= K'.V.C. \cos(\phi - a).$$

$$\text{Since} \qquad \phi - a < \phi, \quad \text{therefore} \quad \cos(\phi - a) > \cos\phi.$$

It thus follows that the torque exerted is too large, and the meter runs fast and, consequently, registers too high.

$$\text{When} \qquad \phi - a = 0 \quad i.e. \quad a = \phi$$

$$\text{then} \qquad \cos(\phi - a) = 1$$

$$\text{and} \qquad D = K'.C.V.$$

The meter in this case registers as though the current C and the voltage V were in phase with one another.

When the current leads in advance of the pressure by an angle ϕ, it can be shown in a similar manner that the meter will read low, and will stop when $a + \phi = \frac{\pi}{2}$, when the meter is over-compensated. In this last case, when $a + \phi = \frac{\pi}{2}$,

$$D = K'.V.C. \cos(a + \phi)$$

$$= K'.V.C. \cos\frac{\pi}{2}$$

$$= 0.$$

It will be readily seen that the reverse holds when the meter is under-compensated, *i.e.* $\Phi = \left\{\left(\frac{\pi}{2} - a\right) \pm \phi\right\}$. In this case the meter will read low for a lagging current and high for a leading current.

The Electrical Company's Induction Meter.—The alternating current watt-hour meter for inductive loads, type K.J., of the Electrical Company, Limited, London, is typical of those induction meters in which the 90 degrees phase displacement of the shunt flux from the voltage of the circuit, or the series flux when the main current is in phase with the supply pressure, is obtained by the employment of an impedance coil and a non-inductive resistance in the pressure circuit of the meter. In this case the non-inductive resistance is placed in parallel with the pressure windings, which are connected in series with the impedance coil direct across the supply mains. The whole shunt current, lagging behind the supply voltage, passes through the im-

pedance coil and divides into two portions, of which the one flows through the non-inductive resistance and the other traverses the pressure coils of the meter.

The method by means of which an exact quarter-phase displacement between the shunt flux and the supply pressure is obtained will be understood by reference to the vector diagram, Fig. 113, on the right of which is shown diagrammatically the pressure circuit of the meter.

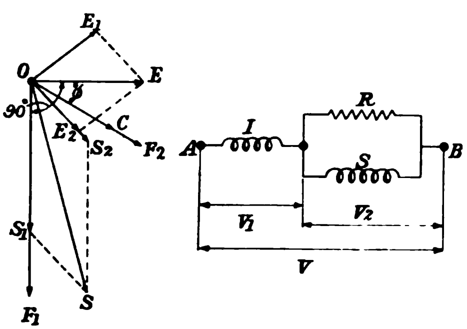

Fig. 113.

O E represents the voltage V across the terminals A and B of the pressure circuit, and O E_1 and O E_2 are respectively the voltages V_1 and V_2 across the impedance

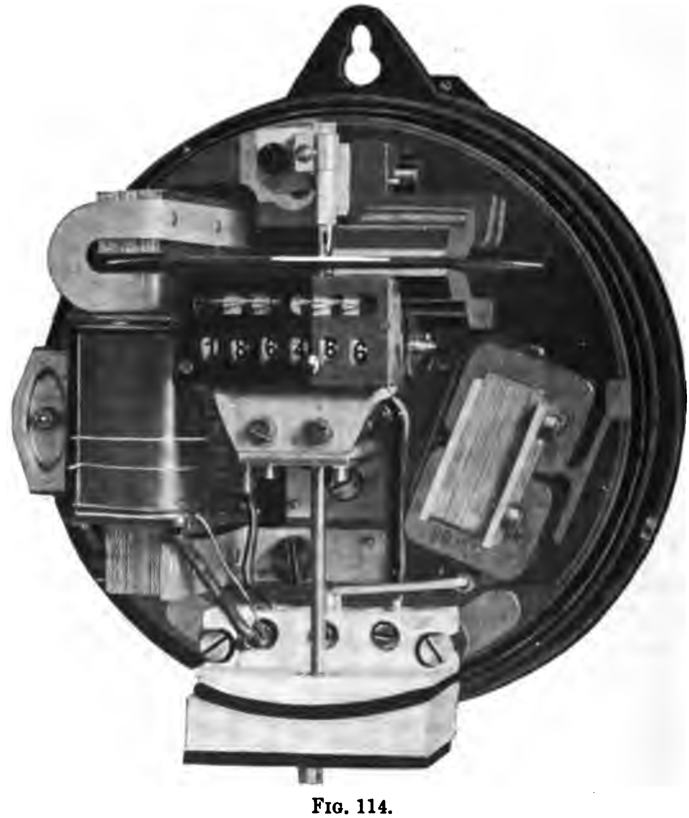

Fig. 114.

coil I and the parallel circuit, composed of the pressure winding S and the non-inductive resistance R. O S is the total shunt current in the

choking coil, and, in consequence of its high self-induction, it lags considerably behind the voltage V_1 across its terminals. This current splits up into the two portions O S_1 and O S_2, of which O S_1 is the current in the pressure winding

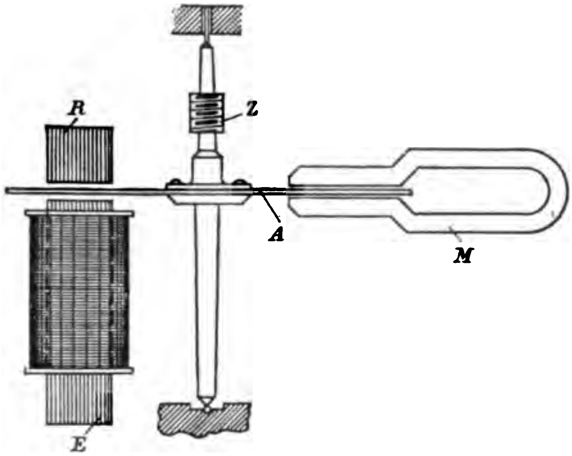

FIG. 115.

lagging behind the voltage, also on account of its self-induction, and O S_2 is the current in the non-inductive resistance, practically in phase with V_2. O F_1 is the shunt flux, due to the current O S_1 in the pressure winding. By properly

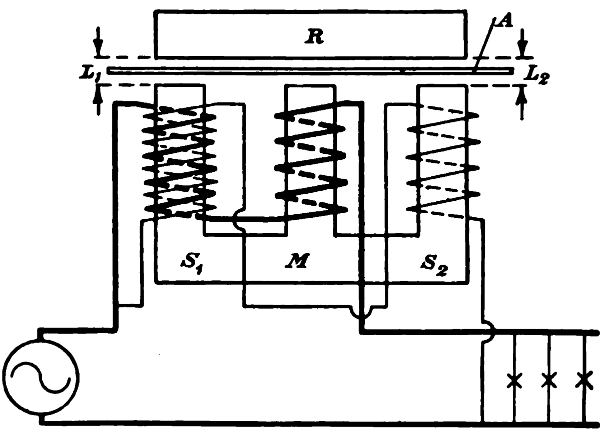

FIG. 116.

choosing the resistance R and adjusting the self-induction of the impedance coil I, a phase displacement of exactly 90 degrees can be obtained between O F_1 and O E. O C represents the main current C in the circuit, supposed lagging behind the supply pressure by an angle ϕ, and O F_2 is the main current flux to which it gives rise. The power supplied to the circuit is in this instance V.C. cos ϕ, where V is the supply voltage and C is the main current,

as given respectively by a voltmeter and ammeter, and cos ϕ is the power factor. The driving torque exerted by the series and shunt fluxes on the disc is proportional to the product of these two fields multiplied by the sine of the angle of phase displacement between them. The shunt flux is proportional to the pressure and the series flux to the main current, and, further, the angle of phase displacement between the two fields, with the above condition of quadrature fulfilled, is the complement of the angle by which the main current lags behind the pressure, and therefore the sine of this angle is equal to cos ϕ. The driving torque is thus proportional to V.C. cos ϕ, or the true power, and the revolutions of the meter executed in a given time will be a measure of the true energy delivered in that time.

The disadvantage of the above method of connection is, that in the non-inductive resistance a large part of the energy used in the pressure circuit is wasted in heat.

The meter, with the cover removed, is illustrated in Fig. 114, and its various parts are shown diagrammatically in Figs. 115 and 116. The revolving element consists of a light aluminium disc A, mounted on a vertical spindle, which rests in a flexibly supported ball-bearing. The disc rotates between the yoke R and the poles of the electro-magnet E, and its speed is controlled by the permanent magnet M in the usual manner. The worm Z, on the upper part of the meter spindle, drives the cyclometer counter, which registers the consumption direct in B.O.T. units. The rotation of the disc is produced by the electro-magnet E, having three vertical limbs (Fig. 116), on the outer two of which are wound the pressure coils S_1 and S_2, whilst the central limb carries the main winding M of the meter. A few of these main current turns are placed on the limb which carries the shunt coil S_1 to counterbalance the disproportionality between the two outer poles, which would otherwise result from the action of the main current fields. This will be understood by reference to Fig. 117, which is a diagram of the shunt and series fields.

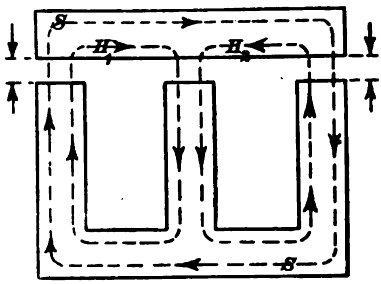

FIG. 117.

The field due to the shunt coils, shown by the dotted lines S S, is affected by the fields H_1 and H_2 produced by the main current coil situated on the central limb. The one shunt pole will be strengthened and the other will be weakened, so that, with increasing load, the former pole will become saturated before the other. To compensate for this inequality the left-hand limb of the electro-magnet has wound upon it a small portion of the main coil, and both the limbs carrying the shunt coils become saturated simultaneously.

On open circuit, the two shunt coils S_1 and S_2 produce a considerable torque if the air-gaps L_1 L_2 (Fig. 116) or the magnetic effects of the two coils are different.

The yoke R is adjustably mounted, so that its relative height above the two outer poles can be altered to compensate for friction on light loads.

Shunt running is obviated by the use of a small piece of bent iron wire fastened to the hub of the armature disc. With no current in the main coils, the wire is held in position by the permanent magnet when it is between their poles, and motion of the disc is prevented. The position of the per-

manent magnet can be altered relatively to the disc for the speed adjustment of the meter.

The Hartmann & Braun Induction Meter.—In the induction meter for inductive loads, manufactured by Hartmann & Braun, Frankfort, Germany,

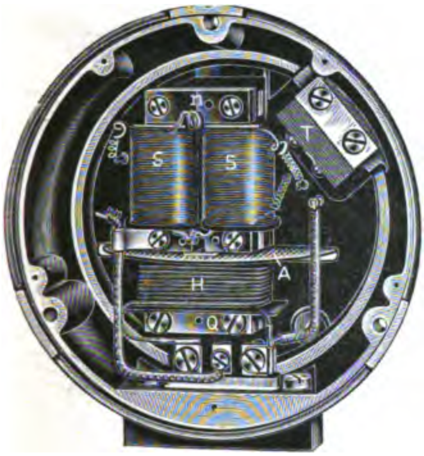

FIG. 118.

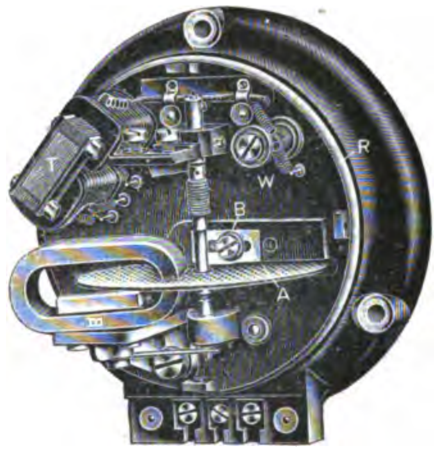

FIG. 119.

the same method of phase compensation is used as in the preceding type. The impedance coil is in series with the shunt or pressure coils of the meter, and the latter are connected in parallel with the non-inductive resistance. Fig. 118 represents the back of the meter with the cover taken off to show the shunt and series system, and Fig. 119 is a front view with the cover and the integrating train removed. S S are the shunt coils wound on the vertical limbs of the laminated shunt magnet *n*, of which the bottom yoke Q carries the main current coil H. In the air-gap between the shunt magnet *n* and the yoke Q is the aluminium armature disc A, which also rotates between the poles of the adjustably mounted brake magnet *m*. T is the choking coil, and W is the non-inductive resistance in the pressure circuit. The aluminium disc A is mounted on a brass tube, which carries at its lower end a highly polished steel pivot running in a jewel spring step-bearing, no clamping device being used. The spindle drives through a worm the integrating dials, shown in Fig. 120, the hands on which all rotate in the same direction, thus facilitating the reading of the counter.

FIG. 120.

At B, Fig. 119, is shown the screw by means of which the friction device

can be adjusted. It consists of an aluminium strip, which projects through the cast-iron base plate between the poles of the shunt magnet and, in general, occupies approximately a mid-position beneath the vertical air-gap separating them. The magnetic lines of force, which are produced by the shunt coils S S, proceed from the poles of the shunt magnet to the laminated yoke Q, in one direction from the one pole and in the opposite direction from the other. The aluminium strip is traversed by some of these lines and in different directions from the different poles, so that the eddies induced in it are opposed in direction, and the fields they produce form rotary fields with the adjacent magnetic shunt flux, exerting a small driving torque on the disc A. With an exact symmetrical position of the strip relatively to the air-gap between the poles, these two rotary fields will be equal and opposite, and their resultant effect on the disc A will be zero. By displacing the strip to a greater or less extent to the left or right, a positive or negative turning movement of definite magnitude is obtained, and is used to compensate for friction, or for any other similar disturbing influences.

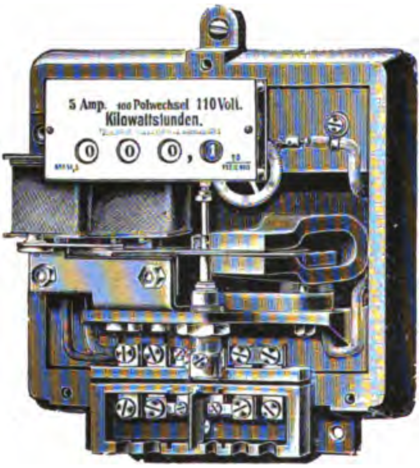

FIG. 121.

The Siemens-Schuckert Single-phase Induction Meter, type W.B.J., for inductive and non-inductive loads, is illustrated in Fig. 121. The revolving element of the meter consists of a light aluminium disc mounted on a vertical spindle provided with a worm, through which the revolutions of the disc are transferred to an integrating train. Rotation is produced by a stationary main current coil and a pair of stationary potential coils. By means of an impedance coil and a non-inductive resistance in series with the pressure circuit of the meter, the angle of phase difference between the series and shunt fluxes can be adjusted to $\frac{\pi}{2}$ when the meter is operating on a load of unity power factor. The main current coil contains no iron, and is arranged under the armature disc with its plane parallel to it, and in close proximity to its edge. It is situated near the poles of the shunt field magnet, and at the back of the same. The two potential coils are wound on the limbs of a laminated iron magnet, having a nearly closed magnetic circuit, with just sufficient space between the right-hand limb and the lower yoke for the armature disc to rotate freely. Attached to the left-hand limb of the shunt magnet is a movable arm with a piece of iron. It is placed above the armature disc, and can be moved nearer to or further away from the poles of the shunt magnet to compensate for the friction of the meter at light loads. According to its position it produces a more or less powerful rotation of the armature disc by its attraction of the eddy currents induced in the disc by the shunt magnet. The armature rotates between the poles of a permanent magnet, and thus also acts as a Foucault brake. The permanent magnet can also be adjusted relatively to the disc to alter the speed of the meter, if necessary. For

purely non-inductive loads, as incandescent lamps, the construction of the meter is simplified, in which case the inductance coil is not used.

The Siemens-Schuckert Werke also manufacture an induction motor meter, type W, on the Ferraris principle, with a symmetrical arrangement of the magnetic and electrical system. The meter is represented diagrammatically in Fig. 122. The stator *a* is built up of thin iron sheets and has four inwardly projecting poles, of which *e e* are wound with the two pressure coils, while the poles *f f* are energised by the two main current coils. A light pivoted aluminium drum *b* forms the armature or rotor of the motor. It surrounds the fixed iron core *c*, and revolves in the air-gap between the pole-pieces and the iron core under the action of the rotary magnetic field which is produced by the shunt and series fluxes. The brake system is situated above the motor, and is composed of two sets of magnets and an aluminium brake disc, ribbed to increase its rigidity. The phase displacement of 90 degrees, when the current and E.M.F. are in phase, is obtained by a special arrangement of the pressure coils of the meter and three non-inductive resistances, so as to form a Wheatstone's bridge, together with a resistance coil in series with the bridge.

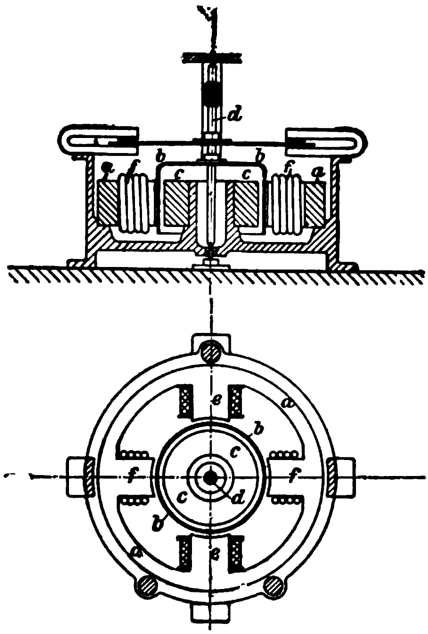

FIG. 122.

The method will be understood by reference to the vector diagram in Fig. 123, and to the diagram of connections of the electrical circuits of the meter given in Fig. 124. In the latter, M_1 and M_2 are the main current coils, and A B and C D are the two pressure windings of the meter. A D, D B, and B C represent the non-inductive resistances, forming with the shunt

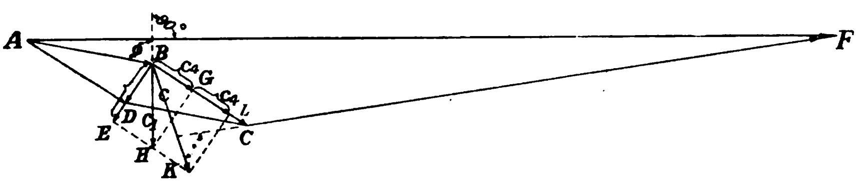

FIG. 123.

coils A B and C D the Wheatstone's bridge, which is connected in series with the inductance coil I, and E and F are the pressure terminals. The shunt flux is created by the coils A B and C D; and its intensity can be varied by altering the resistances of the two branches A D and B C, which are equal to one another. The greater these resistances, the more intense will be the shunt fields, and the sensitiveness of the meter will be correspondingly

increased. The phase adjustment is made by varying the diagonal resistance B D. Increasing the resistance of this branch circuit will produce a diminution in the phase angle below 90°, and by increasing its resistance the phase displacement will be varied above this amount.

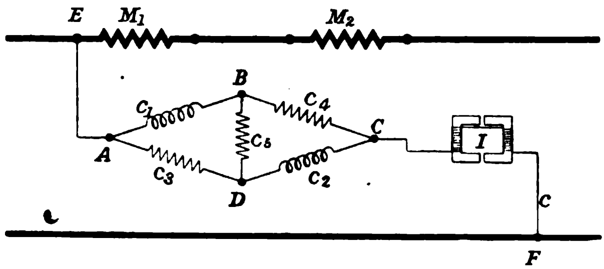

FIG. 124.

If c_1 and c_2 denote the currents in the pressure coils A B and C D, and the currents in the branches A D, D B, and B C be severally c_3 and c_5 and c_4, and, lastly, assuming c to be the total pressure current flowing through the impedance coil I, then

$$c_1 = c_4 + c_5 \quad . \quad \text{(i).}$$

$$c_2 = c_3 + c_5 \quad . \quad \text{(ii).}$$

also $c = c_1 + c_3$ and $c = c_4 + c_2$.

It thus follows that

$$c = c_3 + c_4 + c_5 \quad . \quad . \quad \text{(iii).}$$

It is arranged that

$$c_3 = c_4 \quad \text{and, therefore,} \quad c_1 = c_2$$

so that $\quad c = 2c_4 + c_5$.

FIG. 125.

In the vector diagram, Fig. 123, A B represents the voltage across one pressure coil, B C the voltage across one lateral resistance of the bridge, and B D is the voltage across the ends of the diagonal resistance. The voltage across the inductance coil is given by C F, and A F denotes the pressure across the pressure circuit E F of the meter. The currents $c_5 = \text{BE}$ and $c_4 = \text{BG}$ together combine to the current $c_1 = \text{BH}$, which is displaced by an angle ϕ relatively to its pressure A B. The total current of the bridge, $c = \text{BK}$, is obtained from $c_5 = \text{BE}$ and $2c_4 = \text{BL}$. As now the current $c_1 = \text{BH}$ is to be at right angles to the terminal pressure, the direction A F is given perpendicular to B H. To complete the diagram, the pressure between the terminals of the impedance coil I must be included, and is represented by the length C F. As will be seen from the diagram, the pressure C F is displaced relatively to the total shunt current $c = \text{BK}$ by an angle $\psi < 90°$, so that the desired result can be accurately obtained. In the meter (Fig. 125) the non-inductive resistances and

the impedance coil are combined together and mounted in the instrument above the terminals.

The friction of the revolving element is to a great extent eliminated by means of a special contrivance, termed a vibrator. The jewel footstep-bearing is supported on a spring, attached to which is a small iron armature, which is kept in a vibratory condition by the alternate attractions and repulsions exerted on it by the poles of an alternating current magnet placed beneath it. This trembling action of the whole moving system overcomes the static frictional resistance to motion, and facilitates the starting of the meter, which will commence registering with a load of one-quarter of 1 per cent. of its maximum capacity, and which does not run on the shunt with a 20 per cent. increase in the voltage above the normal.

An auxiliary starting torque may be obtained by displacing the stationary iron core of the motor with respect to the poles for the adjustment for friction on light loads. The core is notched at the opposite ends of a diameter, and, in the symmetrical position in which these notches are exactly opposite the shunt pole-pieces, no effect is produced. When the core is turned out of this position, so that the notches are in an unsymmetrical position as regards the shunt poles, they will exert on the aluminium drum a turning moment which will supplement or oppose the driving torque according to the direction in which the core is turned.

The above types are, however, being superseded by a very simple induction meter, which has recently been introduced by the Siemens-Schuckert Werke. This new meter, type W^2, is suitable for both non-inductive and inductive circuits, and no choking coil is used. Its construction and operation will be followed from Figs. 126 and 127, of which the former represents a front elevation of the meter, and the latter is a diagram of the connections of its circuits.

The driving torque exerted on the aluminium disc S is due to the fields produced by the two main current coils H_1 and H_2 and the pressure coil N, all of which are mounted on the three-limbed electro-magnet E.

The magnetic circuit of the shunt magnet is closed through the top yoke and the case of the meter. The shunt coil N is wound in two sections, as is very clearly shown in the illustrations. The upper, smaller, section (Fig. 127) consists of two portions, of which the one is oppositely wound to the remaining windings of the coil and is connected to a non-inductive resistance V, forming a parallel circuit to the other half of this section. By suitably adjusting the non-inductive resistance V, exact quadrature between the resultant shunt flux and the main current field, when the load is non-inductive, is obtained, and the meter reads correctly whether the current be in or out of phase with the pressure.

The flux produced by the pressure current in the uppermost windings in series with V (Fig. 127) is exactly 180° out of phase with this current, as this part of the shunt coil is oppositely wound to the remainder. The total shunt current flows through the lower section of the shunt coil, and, at its junction with the upper section, gives rise to two components, of which the one circulates round the lower winding of this section and the other round the winding in series with the non-inductive resistance. With the above considerations no difficulty will be experienced in drawing the vector diagram of the meter.

The retarding torque is produced by the rotation of the same disc S between the poles of the permanent magnet B. The revolutions of the meter

spindle A are conveyed through the worm O and the worm wheel P to the jump cyclometer counter Z, which is described in Chapter XIII. The friction compensation consists of a small piece of iron adjustably fixed to a bracket above the armature disc and close to the pole of the shunt magnet.

By altering the position of this iron shading piece relatively to the shunt pole the speed of the meter at light loads can be accelerated or retarded. The arrangement of the terminals is shown in Fig. 126, from which it will be seen that the pressure circuit of the meter is easily isolated for testing purposes

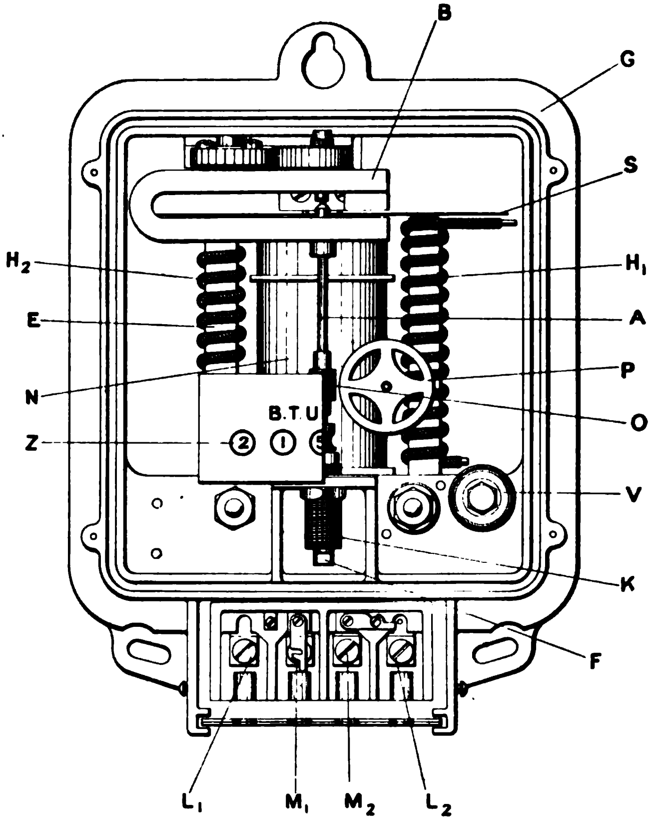

Fig. 126.

without having to remove the main meter cover. To prevent damage during transit the jewel-bearing F can be lowered, and at the same time a spring collar is raised and takes the weight of the revolving element. The W_2 meter is also supplied with a trembling method of support of the revolving element similar to that used in the W type. It is illustrated diagrammatically in Fig. 128. The spindle A revolves on the jewel-bearing F, mounted on the spring D, which is fixed at one end at X. This spring carries the keeper J of the small alternating current electro-magnet U, which is energised by the pressure current. By means of the alternate attractions and repulsions

exerted on the keeper J, the spindle A is kept in a vibratory condition, greatly reducing friction, especially static friction, at the moment when the meter starts from a state of rest to one of motion.

The Deutsch-Russische Induction Meter, made by the Deutsch-Russische Electricitätszähler-Gesellschaft, Germany, differs in many essential details from the majority of the known types of alternating current meters designed on the principle of Ferraris and Thomson.

In these cases the driving torque is produced by magnetic fields arranged symmetrically or asymmetrically to the axis, and is exerted upon a light revolvable disc or drum of copper or aluminium, which, in the generality of cases, also acts as a brake at the same time, in connection with one or more permanent magnets. In the Deutsch-Russische meter the rotating body driven by the shunt and series systems consists of a light iron ring which is

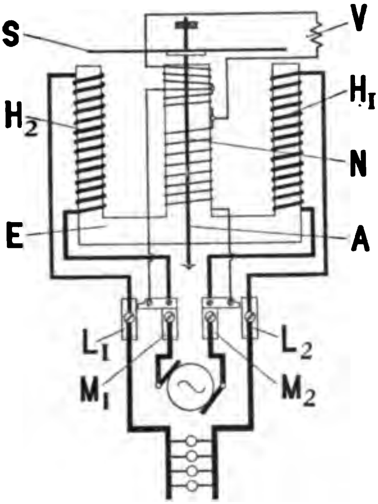

FIG. 127.

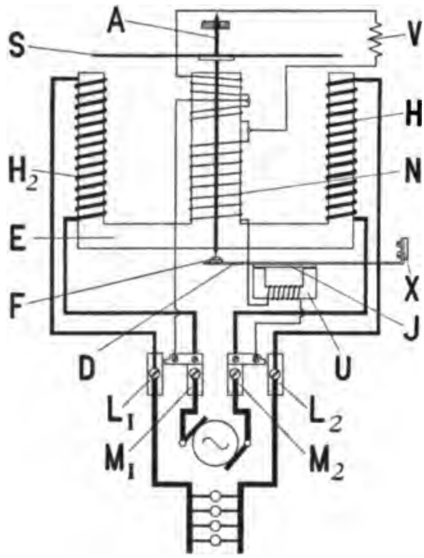

FIG. 128.

built up of a series of thin annular discs and has wound upon it a short-circuited copper coil. The ring is situated below the poles of the shunt magnet, as in this position, when under load, the whole revolving system partially floats, whereby bearing friction is materially diminished.

The shunt magnet and ring are placed symmetrically between the two series coils, as will be readily seen from the view of the instrument with the cover removed given in Fig. 129. Only a small amount of iron is used in the shunt field, and none at all in the main current coils, so as to exclude the choking effect of the iron from the same. An aluminium disc carried on the lower extremity of the meter spindle rotates between the poles of one or more permanent magnets and constitutes the Foucault brake. With this arrangement the permanent magnets are placed well beyond the disturbing influence of the varying fields produced by the shunt and main currents. The construction of the meter is shown more in detail in the plan and side elevation in Figs. 130 and 131 respectively. H_1 and H_2 are the two main

10

current coils; they are rigidly fixed to the meter base and contain no iron. In between them is situated the laminated shunt magnet J, the vertical limbs of which support the two shunt coils N_1 and N_2. Below the poles of the horseshoe magnet is the iron armature ring R, carried on the vertical spindle C, on the lower part of which is mounted the aluminium brake disc A rotating between the poles of the permanent magnet M. The revolutions of the meter are transferred by means of the worm S to the counter Z having jumping figures. The lines of force of the shunt magnet, the current in the coils of which lags behind the voltage of supply, traverse in semicircular paths the iron ring of the rotating armature from one pole to the other, and this flux takes place in the magnetic field of the main current coils, which

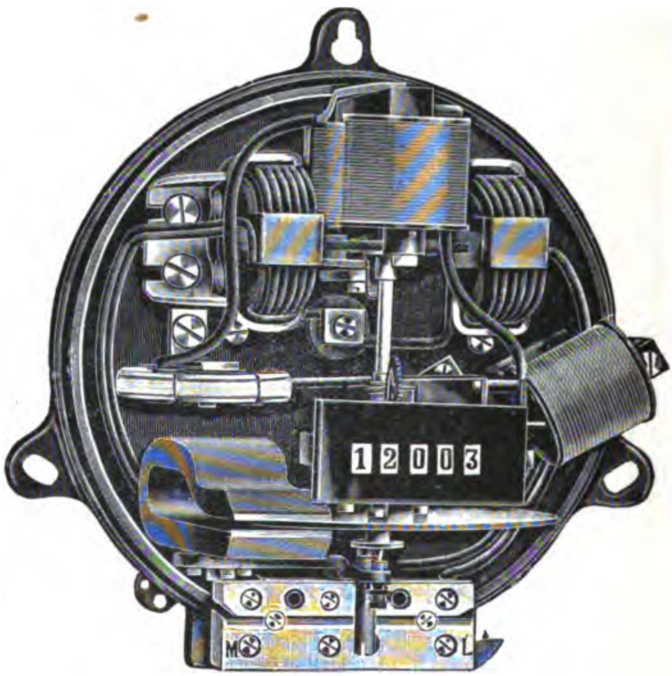

FIG. 129.

field is slightly distorted by the iron ring, as in a gramme ring armature, but otherwise extends in straight lines from coil to coil.

The two magnetic fields are in one plane and cross one another, but do not cut the revolving element at right angles to the plane of rotation, as on the Ferraris and Thomson principle.

The 90 degrees displacement between the shunt and series fluxes, when the load is non-inductive, is obtained by the employment in the pressure circuit of the reactance coil D D in conjunction with a non-inductive resistance V W.

The two main current coils are connected in series to the main current terminals of the meter, as clearly shown in the illustration. The pressure circuit of the meter consists of two parallel branches. The two shunt coils

are in series with one of the two windings of the choking coil, and this circuit is placed in parallel with the second circuit comprising the remaining winding of the choking coil in series with the non-inductive resistance. The shunt current in the meter divides into two portions, of which the one traverses the shunt coils and one reactance coil, and the other flows through the second reactance coil in series with the non-inductive resistance. By suitably adjusting these two branches the desired phase relationship will be obtained.

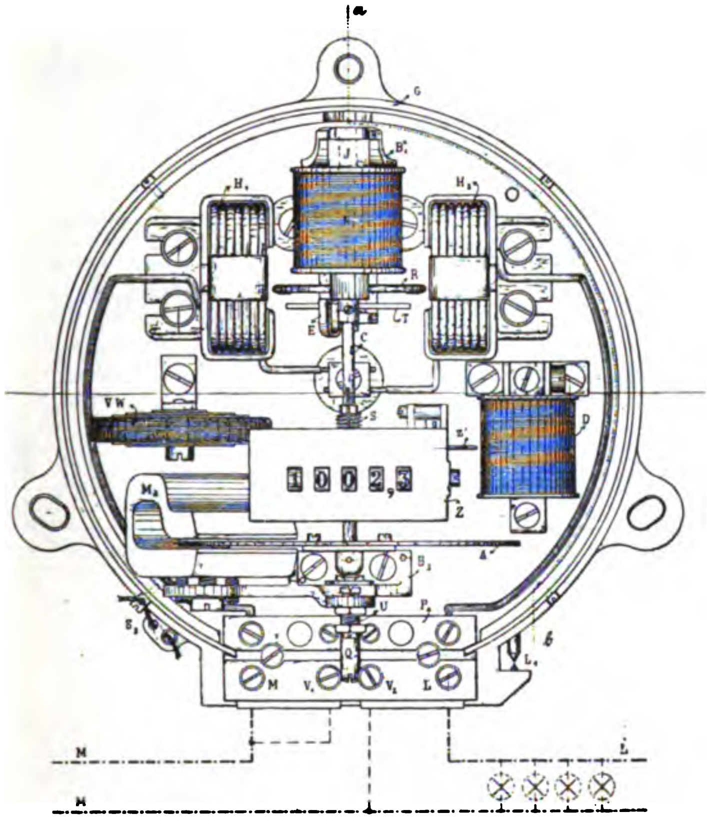

FIG. 130.

The speed of the meter at full load is regulated in the usual manner by adjusting the brake field.

The friction compensating device consists of a small iron stirrup E placed below and on one side of the armature ring R. It is pivoted to one of the pole-pieces of the shunt magnet J by means of paramagnetic material. The method of adjustment on light loads is exceedingly simple and can be performed with the meter in position without unsealing the meter cover. This starting control is separately illustrated in Figs. 132, 133, and 134. On the meter cover K (Fig. 134) is a small pivoted lever Y, which can be independ-

ently sealed. By displacing the lever, access is obtained to the screw X, which carries a pinion gearing with a toothed sector T. When the screw is turned,

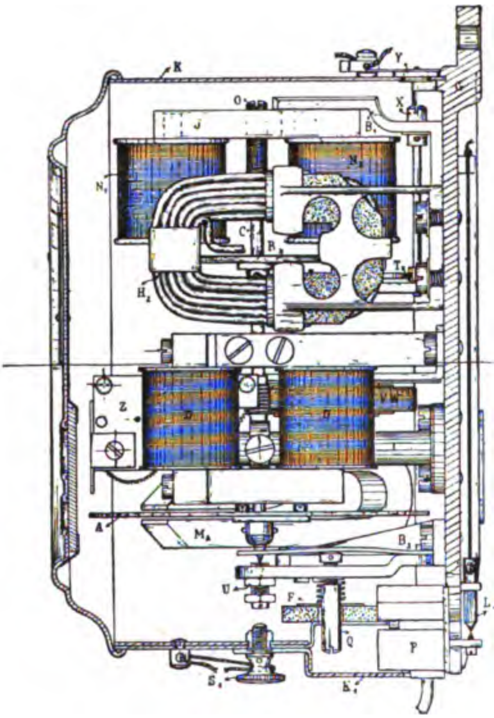

FIG. 131.

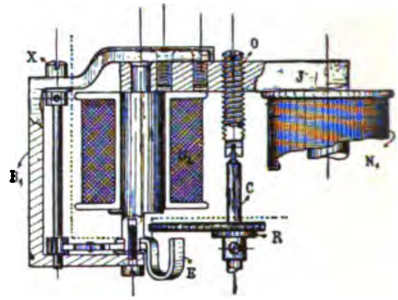

FIG. 132.

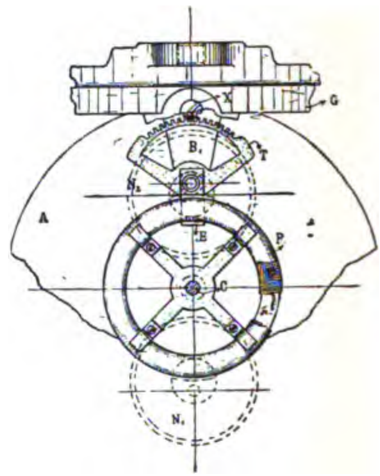

FIG. 133.

E is moved to the right or to the left through the sector T, and with the ring R exerts a supplemental torque on the one side of it. This auxiliary turning moment either assists or is in opposition to the driving torque exerted on the ring, and so either augments or decreases the starting of the meter.

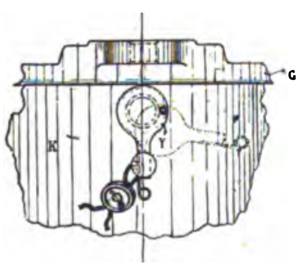

FIG. 134.

For purely non-inductive loads, such as incandescent lamps, the meter is simplified, in which case the choking coil is dispensed with.

The Mix & Genest Induction Meter.—Messrs Mix & Genest, Berlin, in their meter, type A.W., for inductive and non-inductive loads, also obtain the 90 degrees phase displacement between the two fluxes driving the meter disc, when the power factor of the circuit is unity, by means of a non-inductive resistance and a reactance coil in the pressure circuit. The meter is illustrated

in Fig. 135. The stator consists of two main current coils, containing iron, and a shunt magnet, energised by one pressure coil, and having an almost closed magnetic circuit but for the narrow air-gap in which the aluminium disc rotates. The plane of the shunt magnet is perpendicular to that of the main current magnet.

An impedance coil is used in the pressure circuit, and is connected in series with the adjustable non-inductive resistance and the shunt coil.

The disc rotates between the poles of two adjustable permanent magnets, and the revolutions of the spindle are conveyed to an integrating train in the usual manner. The pressure circuit of the meter is specially well subdivided, and by the use of two shunt terminals it can be easily isolated from the main circuit without disturbing the main cover. A high driving torque per unit weight of the armature is obtained in this meter, amounting to very nearly 2·86 mm.-grms. per gm. of the revolving element, as will be seen from the figures given in Table III. on page 14.

FIG. 135.

The Hookham Alternating Current Meter, for non-inductive loads only, is illustrated in Fig. 136.

A is the aluminium disc, which is rotated by the fields produced by one pressure and two main current coils. It is carried on the vertical spindle B, which rests in a lower jewel-bearing C. The pressure coil E is wound on an iron magnet D, and the main current coils consist of two flat spiral coils F joined together in series, and placed between the poles of the shunt magnet and below the armature disc A.

In the front view given of the instrument only one main current coil can be seen, as the other is situated behind it. The work done by the meter is absorbed in the eddies induced in the revolving disc A by the permanent magnet on the right. The dials register direct in units and are driven in the usual manner from the meter spindle. The upper poles G G of the magnet D are adjustable, and may be either raised or lowered to effect the friction compensation of the meter at light loads.

The Westinghouse Induction Watt-hour Meter is the representative type of those alternating current meters for inductive loads in which the phase compensation is secured by the employment of a closed secondary winding on the shunt electro-magnet. The pressure circuit of the meter is made highly inductive, so that the shunt current and the shunt flux, to which it gives rise, lag behind the impressed E.M.F. by a considerable angle, which, however, is always less than a right angle. This angle is artificially increased to 90 degrees by means of the secondary winding, in which is induced a secondary current producing a flux lagging behind the shunt current by an angle greater than 90 degrees. These two fluxes combine to a resultant shunt flux, and by properly adjusting the conductivity of the secondary circuit this resultant flux will be displaced by a right angle from the impressed E.M.F. or the main current flux when the load is non-inductive. The meter then registers correctly at all power factors.

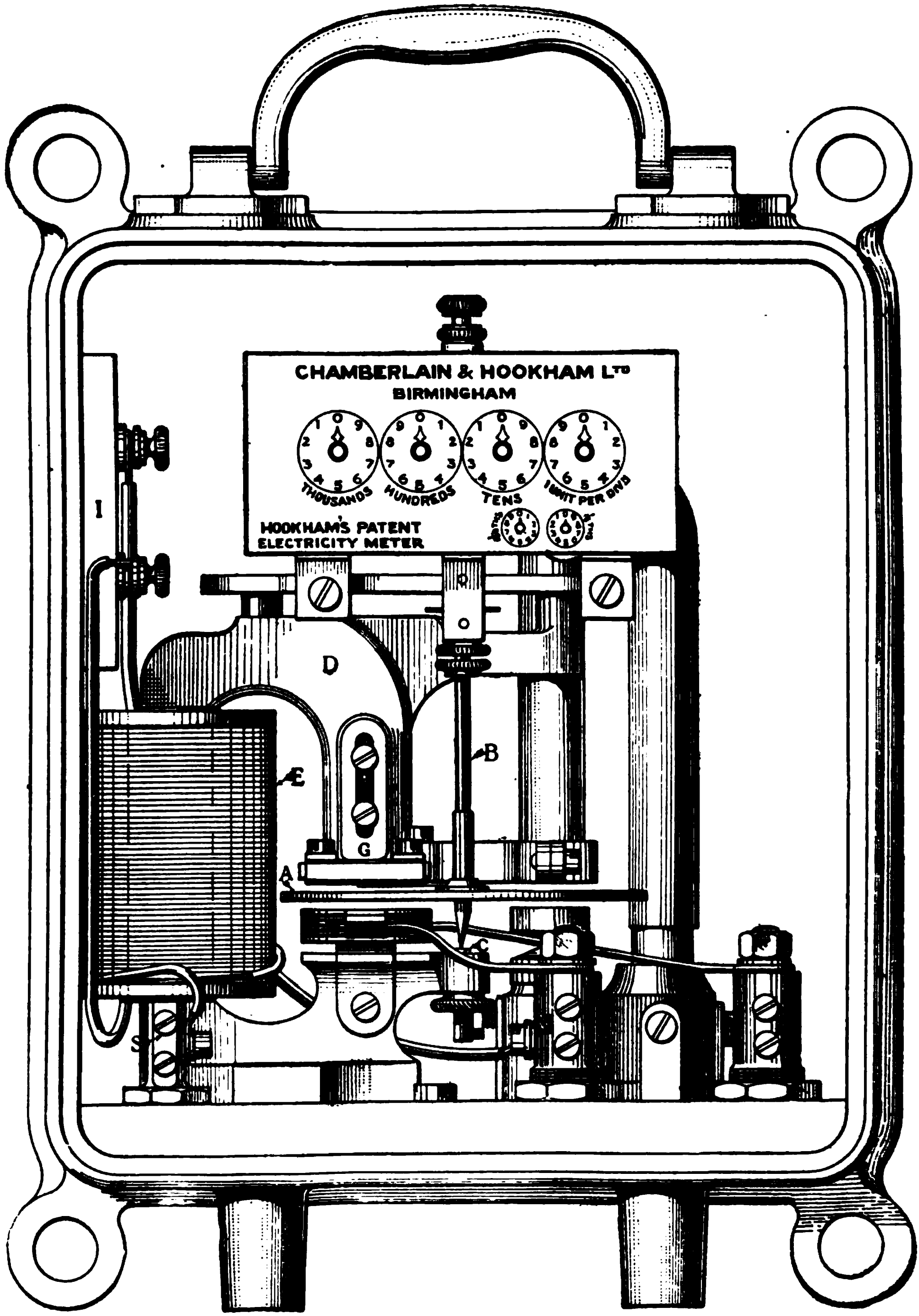
CHAMBERLAIN & HOOKHAM LTD
BIRMINGHAM
THOUSANDS
HUNDREDS
TENS
1 UNIT PER DIV
HOOKHAM'S PATENT
ELECTRICITY METER
I
D
B
E
G
A
C

FIG. 186.

Fig. 137 is a vector diagram showing the relationship between the different magnetic fields of the meter.

O E represents in magnitude and direction the impressed E.M.F., and O S is the shunt current producing the shunt flux O F_1, practically in phase with O S, and lagging behind O E by an angle θ equal to 80° or 85°. O C is the current in the secondary circuit, and O F_2 is the flux to which it gives rise, and which lags behind O F by an angle greater than a right angle. OF is the resultant of O F_1 and O F_2 at right angles to O E. O B is the main current, assumed leading in advance of the E.M.F. O E by an angle ϕ, and O A is the main current flux, very nearly in phase with O B. The torque exerted on the revolving armature disc by these two fields is proportional to their product multiplied by the sine of the angle of phase difference between them. This angle, with the above conditions of exact quadrature fulfilled, is $90° + \phi$, and its sine is equal to $\cos \phi$, the power factor of the circuit. The shunt flux is proportional to E, the impressed E.M.F., and the main current flux is proportional to the main current C. The result is, that the torque is proportional to E.C. $\cos \phi$, the true power in the circuit, and the

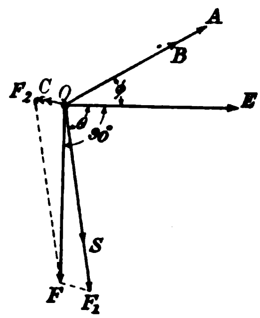

FIG. 137.

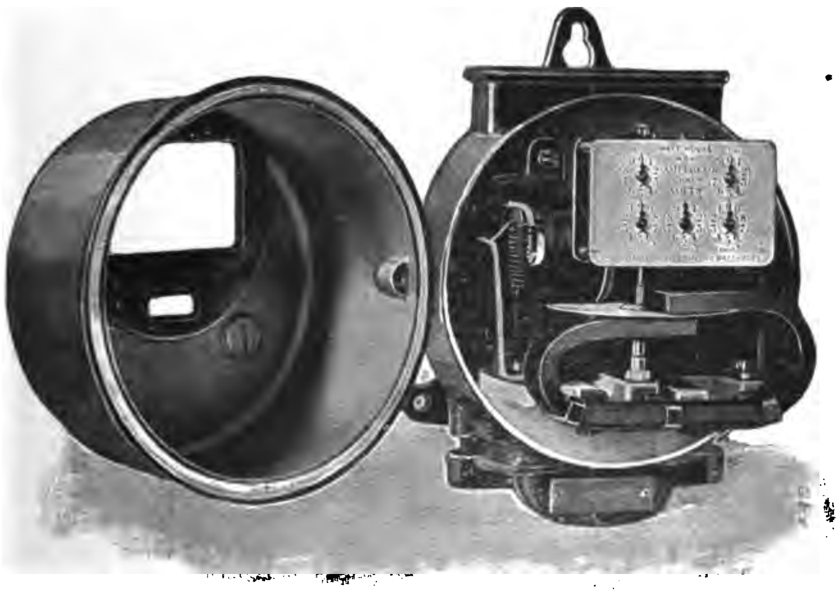

FIG. 138.

revolutions of the meter disc executed in a given time will be directly proportional to the true energy delivered in that time.

Fig. 138 is a view of the Westinghouse meter, 'Round' type, with the cover open. The revolving element consists of a light aluminium disc

mounted on a short vertical spindle, the upper end of which drives the integrating train in the usual manner, while the lower end runs in a jewel step-bearing. The meter dials register direct in Board of Trade units without the use of a multiplier or constant. The rotation of the disc is produced by means of a shunt and series system illustrated diagrammatically in Fig. 139. The shunt and series coils are wound on an electro-magnet having a double magnetic circuit with a horizontal air-gap H, in which rotates the armature disc A, and with the two upper poles separated by a small vertical gap V. The shunt or pressure winding consists of two coils S S, one on each limb of the electro-magnet, and it is connected in series with an impedance coil I of fine wire, wound on an iron core fixed in the meter base. When the pressure circuit is energised by an alternating current, two equal and adjacent (alternating) poles of opposite polarity are produced, the effect of the one neutralising the effect of the other as regards any action on the disc. The iron core is magnetised as a simple ring by the alternating magnetic flux, which

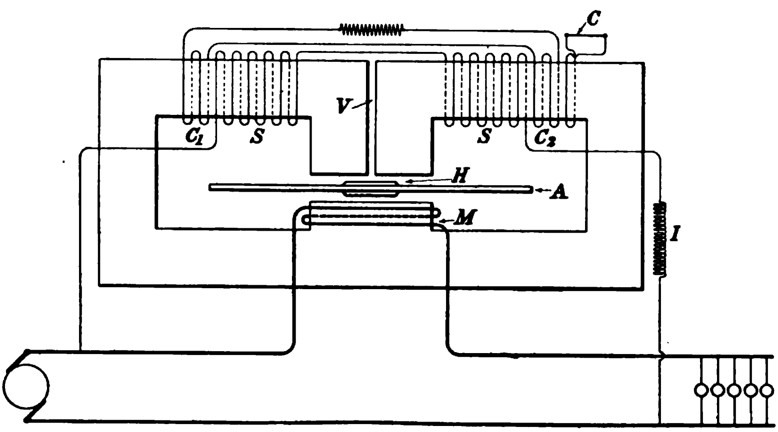

FIG. 139.

for the most part bridges the small vertical gap V, and only a very slight leakage takes place across the gap H.

The series or main current coil M consists of a few turns of thick insulated wire wound on the lower pole, and is connected direct in one of the supply mains. When current flows in this coil it tends to produce adjacent poles of the same polarity. The result is, that with both the pressure and main current coils energised the resultant flux in one magnetic circuit of the electro-magnet is the geometrical sum, while in the other it is the geometrical difference of the two fluxes due to the pressure and current windings.

In this manner a shifting magnetic field of varying intensity is obtained in the horizontal air-gap H, producing rotation of the disc. The retarding torque proportional to the speed is obtained by means of a permanent magnet, between the poles of which the disc moves.

C in the diagram (Fig. 139) is a small closed secondary circuit for the purpose of adjusting for running friction. In the actual meter, 'Round' type, this consists of a single turn of copper wire on one limb of the electro-magnet (the right limb seen from the front), and is short-circuited through a piece of resistance wire. The effect of this circuit is to slightly unbalance

the magnetic fields in the two limbs of the electro-magnet, producing a tendency on the part of the disc to rotate. The length of the resistance wire is then adjusted until this tendency is just sufficient to overcome the friction.

The secondary winding, by which the phase compensation is obtained, consists of an equal number of turns C_1 and C_2 (Fig. 139), wound on each limb of the electro-magnet, connected in series, and short-circuited through a resistance wire in the same manner as in the case of the friction adjustment. The resistance is then regulated until the desired phase relationship between the shunt and series phases is obtained.

Fig. 140 represents an interior view, with the integrating dial removed, of the latest instrument, known as the 'Sub-A' meter, in which the phase and friction compensations are on the same principle as those just described, but are somewhat differently carried out. The British Westinghouse Company, Trafford Park, Manchester, use four terminals in the English meter instead of three, as shown in Fig. 140, which is the type manufactured by the Westinghouse Co., Pittsburg, U.S.A. Two of these terminals are for the pressure circuit and the other two for the main current winding,

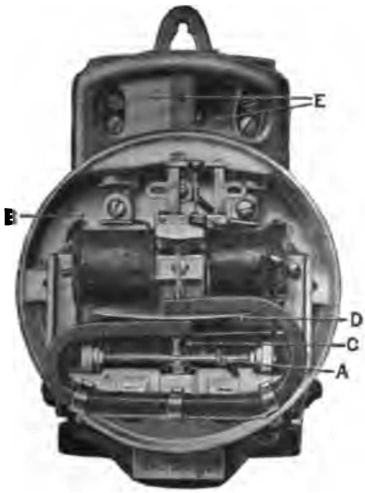

FIG. 140.

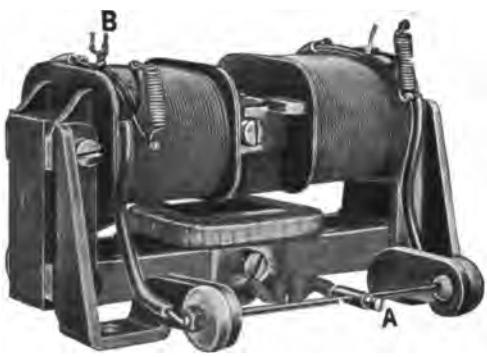

FIG. 141.

and one shunt and one current terminal are connected together by means of a link, which can be removed to isolate the pressure circuit for testing the meter.

Fig. 141 is an illustration of the shunt and series electro-magnetic system of the 'Sub-A' type, showing the phase and friction compensations. It applies equally to the two- and three-wire meters, the difference in the latter case being in connection with the terminal chamber, the external form of the meter, and that the series coil is wound in two sections, insulated from one another, each section being placed in one of the outers of the system.

The outer ends of the secondary windings, which consist of an equal number of turns on each limb of the electro-magnet, are brought to the extremities of a piece of resistance wire, the inner ends of the windings, or those in close proximity to each other, being joined together and brought to a sliding connector A (Figs. 140 and 141), which is set about the middle of the resistance wire. If the connector be moved from the middle of the wire, the resistance of one half of the secondary winding is increased, the other being decreased, thus upsetting the balance of the magnetic circuits. By this

means the friction adjustment is obtained. To adjust the series and shunt fluxes to exact quadrature when the current and E.M.F. are in phase with one another, a resistance is inserted in the secondary windings, so as to be common to both halves of the circuit, and the resistance is altered until the desired phase relationship is obtained.

The speed control is made by moving the position of the permanent magnet relatively to the rotating aluminium disc D (Fig. 140). If the magnet be moved out from the disc, the speed will be increased at any given load, and *vice versa*. The frequency adjustment is shown at B (Figs. 140 and 141).

Meters which are sent out calibrated for circuits having a periodicity of 133⅓ cycles per second are arranged so that they may be changed to 60 cycles per second by soldering together the two wires shown at B and changing the connection at the rubber terminal block below the electro-magnet to the point marked 7200. The meter should then be checked and adjusted for speed.

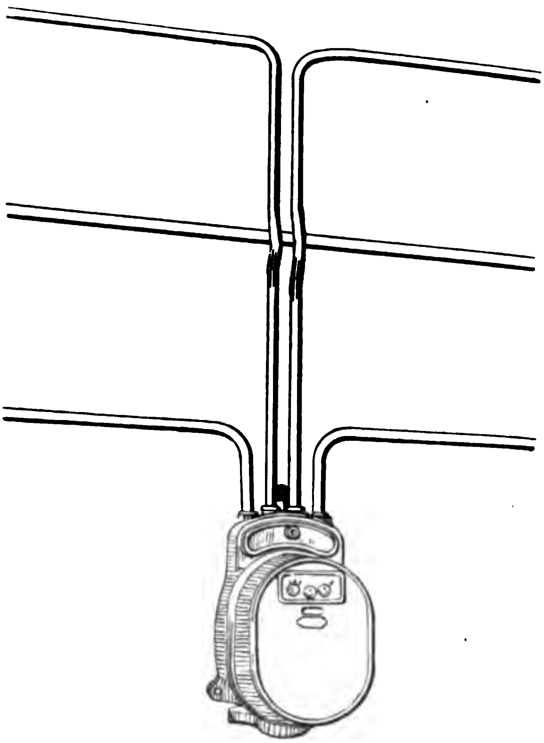

FIG. 142.

In Fig. 142 is given a diagram of connections of the three-wire meter.

All the Westinghouse meters are so designed that, whatever the capacity, the disc rotates at the rate of 50 revolutions per minute on full load, and in consequence a meter can be readily checked with a considerable degree of accuracy by observing the rate of revolution of the disc through the window in the aluminium-zinc cover.

The Aron Induction Motor Meter, Fig. 143, belongs to the class of alternating current meters in which the phase compensation is produced by the use of short-circuited copper pieces surrounding the shunt magnet poles, their number depending on the voltage and periodicity of the circuit.

The driving torque is produced by a rectangular laminated shunt magnet, energised by two shunt coils carried on its vertical limbs, and a series coil wound on an iron core, which is normally situated midway between the two poles and above the aluminium armature disc. The magnetic circuit beneath the disc is closed through a soft iron plate, which can be displaced relatively to the poles. The main current coil with its core can also be moved nearer to either one or other of the two poles of the magnet as desired. These two

alterations in position of the lower yoke and the series coil can be used to effect the low load or friction compensation, the final adjustment of which is usually made with the lower yoke.

The retarding torque is obtained from the action on the same disc of the permanent magnet, situated on the right of the shunt and series system. The keeper of the permanent magnet is mounted on a horizontal support below the disc, and can be raised or lowered so as to decrease or increase the air-gap in which the disc rotates. In this manner the speed of the meter is adjusted at the high loads without altering the position of the brake magnet. The revolutions of the meter spindle are transferred in the usual manner to the integrating counter, which has springing figures. The counter also has two small dials in hundredths and thousandths of a unit for testing purposes, but which are not visible when the case is on. In future patterns it is intended to supply a small window through which these dials can be observed without removing the cover, the window being provided with a small sliding cover of its own, arranged so that it can be sealed.

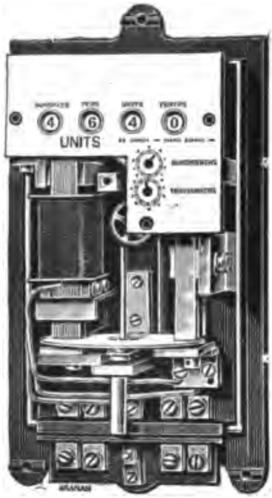

FIG. 143.

The 'Bat' Electricity Meter furnishes another example of an induction meter suitable for both inductive and non-inductive

FIG. 144.

FIG. 145.

loads, in which the lag compensation is obtained by means of short-circuited rings of copper on the poles of the magnet. A general view of the instru-

ment is shown in Fig. 144. The revolving element consists of the usual disc mounted on a vertical axle having a worm to actuate the integrating train of dials. The disc is of hard drawn copper and is of somewhat unusual thickness, the object being to obtain not only a high conductivity for electrical purposes, but to prevent bending by shocks in transit, and to resist the twisting action exerted on the disc by a short-circuit current. In connection with a permanent magnet it also constitutes the customary magnetic brake. The driving torque is derived from the fields produced by six coils, of which four comprise the main current coils and the remaining two are the pressure coils. The driving system used in this meter is separately illustrated in Fig. 145. The pressure coils are wound on the two vertical limbs of a horseshoe magnet, composed of soft iron stampings, the pole-pieces of which are short-circuited by a laminated iron bridge.

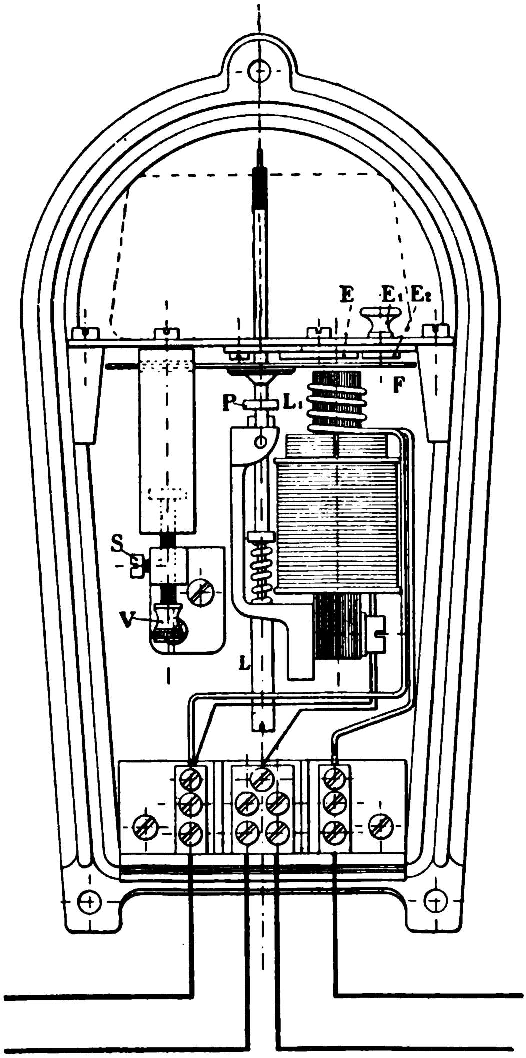

FIG. 146.

These poles are extended beyond the bridge, and each is divided into two halves, forming four poles in all, upon which are wound the four main current coils in series, as depicted in the illustration. The pole-pieces also carry the short-circuited copper rings already referred to. With the arrangement adopted the shunt coils have a large self-induction, and by suitably adjusting the short-circuited copper rings the main current and pressure current fluxes will be displaced in phase by 90 degrees when the meter is registering on a load of unity power factor.

A characteristic feature of the meter is the simple and efficient method provided for adjusting the speed at top load down to one-third of full load. The position of the brake magnet is invariable, and the intensity of the brake

field is altered by increasing or decreasing the leakage of the permanent magnet.

The amount of the leakage that takes place is controlled by an iron screw V, Fig. 146, mounted on the base of the meter. This screw is raised or lowered, decreasing or increasing the air-gap separating it from the lower pole of the magnet. Screwing up V will cause the meter to run faster, as more lines of force will, in this manner, be shunted from the brake field in which the disc revolves.

When the adjustment has been finally accomplished, any further motion of V is prevented by tightening the clamping screw S. For lower loads, under one-third full load, the friction compensation is effected by altering the position of the iron plate E through the knob E_1. The iron plate acts upon the Foucault currents in the disc, and if moved forward will cause the meter to go faster.

The brake magnet is shielded from the disturbing influence of excess currents by the casting which supports the electrical elements of the meter. This casting is also furnished with a tapped hole to receive the screw which secures the meter cover to the base.

FIG. 147.

The Brush-Gutmann Single-phase Induction Watt-hour Meter, manufactured by the Sangamo Electric Company, Spingfield, Illinois, U.S.A. (the Brush Electrical Engineering Company, London), embodies many novel features in its electrical and mechanical design. A side view of the meter with the cover removed is given in Fig. 147. It consists of a laminated shunt magnet and a small pair of series coils, the magnetic fluxes of which operate upon a light aluminium disc, slotted in peculiar spiral curves. The speed of the disc is controlled by a permanent magnet in the usual manner, and is transferred to an integrating train through a worm, constructed of a special non-rusting alloy, on the upper extremity of the steel spindle. The revolving element is illustrated in Fig. 148, which very clearly shows the driving worm and these spiral slots of the armature, by means of which an increased torque is claimed to be obtained.

The shunt and series motor system is also given in detail in Fig. 149. The laminated steel magnet E is energised by the shunt coil V, and is composed of two parts, the main magnet body and the bridge J. This bridge, or lower yoke, completes the magnetic circuit of the main magnet through the front air-gap, in which the armature disc rotates, and a second narrow gap at the back, so that it does not make actual magnetic contact with any part of the main magnet. Although the two air-gaps add slightly to the resistance of the main magnet, a large magnetic flux is obtained with a high self-induction of the shunt coil. The bridge performs an important function as regards the phase compensation for inductive loads. Almost surrounding the bridge, except for

a narrow gap on the lower side, is the phase band, shown at A. This consists of a heavy copper strip, to which is soldered, on each side of the gap, a pair of brass connecting blocks. Each block is drilled through to receive a No. 11 or No. 12 wire, which spans the gap, and is firmly held in position by two small set screws in the blocks.

FIG. 148.

For high frequency meters a No. 13 copper wire is employed, while for 60 cycles per sec. a No. 11 wire is necessary, as a much lower resistance is then required on account of the lower frequency. In a 50 cycle meter the loop usually consists of a No. 10 wire, and of a No. 9 wire in a 40 cycle meter.

FIG. 149.

When the circuit around the yoke, composed of the phase band A and a loop of wire L, is thus complete, the secondary current induced in it, provided it is of the correct resistance, reacts upon the shunt field just enough to cause it to be in quadrature with the main current flux when the E.M.F. and the current are in phase, and the meter speed will be proportional to the true power under all conditions of load. The loop of wire to bridge the gap is long enough to afford a wide range of adjustment in setting the meter for inductive loads. The necessary alteration is easily made by sliding the phase loop in or out of the blocks, and, further, by using loops of different size.

If the meter be found to run faster on an inductive load than on a non-inductive one absorbing the same power, the loop must be moved further out, that is, its length must be increased, or a smaller wire must be used. The phase band is clamped in position on the bridge by the small brass screw B,

and its position has a decided effect upon the speed of the meter on light loads, and particularly at low frequencies. When the band is near the front end of the bridge the meter will tend to run slow, and with the band further back it will run faster on light loads, so that it is of importance to firmly tighten down the holding screw after the adjustment has been made. This effect of the phase compensation may sometimes be useful in aiding the friction device, to be explained later on. As a general rule, the phase band is best clamped at the back end of the bridge after the phase loop has been set.

Two series coils are used in this meter, and are held in small aluminium clamps firmly screwed to the main bracket D D, which supports the shunt and series system. As they have only a few turns, no inductive drop is caused in the main circuit with a heavy load.

In Fig. 150, which is another side view of the meter, is shown the method of supporting the permanent magnet G. It is held in an aluminium clamp C, which is fastened by two screws to the bracket at M. The near screw acts as a pivot and is fixed, while the front one moves in a long slot, so that the magnet jaws can be swung in or out relatively to the disc. The greatest damping effect is obtained when the outer edge of the magnet is just above the edge of the disc.

FIG. 150.

The light load adjustment is made by means of a special friction device, consisting of a long strip of japanned steel. It is secured to the inner side of the laminated magnet at the top, and terminates in a foot at its lower end, as shown at F in Fig. 149, so as to present a larger surface for the leakage of the lines through the disc and back through the bridge beneath. Near its upper end the compensation piece has a small slot through which passes the screw T (Fig. 149), by means of which and the rectangular brass nut N (Fig. 150) it is tightly clamped against the magnet. The strip is raised or lowered by means of the adjusting screw R (Fig. 150), which works vertically against the fixed nut N, and passes through the small nut P to which the strip is soldered. The friction compensation is effected by raising or lowering the strip, or by rotating the foot round T as axis, and rotating it forward will retard the speed of the disc. The most sensitive method is to lower the strip until its foot is near the disc, when a slight lateral movement will produce a marked effect on the speed at light loads.

In this company's small capacity three-wire meter, which consists practically of two meters in one, the lower series coil is connected in one side of the system and the upper coil in the other side, with the full difference of potential between them. The shunt has in this case, as in their 220 voltmeters, a reactance in series with it, and is connected across the outers.

In their three-wire meter for circuits taking above 50 amperes per side

a three-wire series transformer is used, and the shunt is connected between one outer and the middle wire.

The Ferranti-Hamilton Induction Meter.—A special feature of the Ferranti-Hamilton induction meter, illustrated in Fig. 151, is its combination of a sound mechanical construction with a simple electrical design. The parts of the meter are carried on a vertical gun-metal frame screwed to the cast-iron case, from which they can be easily lifted. The terminal box is also well arranged and is placed on the top of the meter. It is provided with two main current and two shunt terminals, one of the latter of which is connected through a small copper hook to a main current terminal, and can be readily disconnected from it without opening the main cover. This is an important consideration in testing a number of meters in series, in which case the shunts must be isolated from the main current terminals to which they are connected, and are all placed in parallel across the testing circuit, the main current coils of the various meters being joined together in series.

Fig. 151.

The working of the meter will be understood by reference to the sectional drawings given in Fig. 152.

The revolving element consists of a light aluminium disc D mounted on a vertical spindle S, which rests on a jewel, set in a removable jewel-screw J.

It rotates in the air-gap separating the shunt and series magnets, and between the poles of the two permanent magnets P M, which are situated at the back of the meter and produce the retarding torque. The spindle is geared to the wheel train C T actuating the index hands, which read direct in B.O.T. units. Below the armature disc is the shunt tubular magnet T M, having an internal core C, upon which is wound the shunt coil Sh.C. The shell of the tubular magnet has four inwardly projecting radial poles P_1, which alternate with the outward radial poles P_2 of the magnet core. These two parts of the magnet are separately shown in Fig. 153.

No choking coil and resistances are necessary, as the type of magnet used provides a highly inductive shunt circuit.

Iron washers W, surrounding the shunt magnet, are used to adjust the meter on different frequencies, and the lower the frequency the more washers are required. They also constitute the lag compensation for producing the

desired phase displacement between the series and shunt fluxes when the E.M.F. and current are in phase.

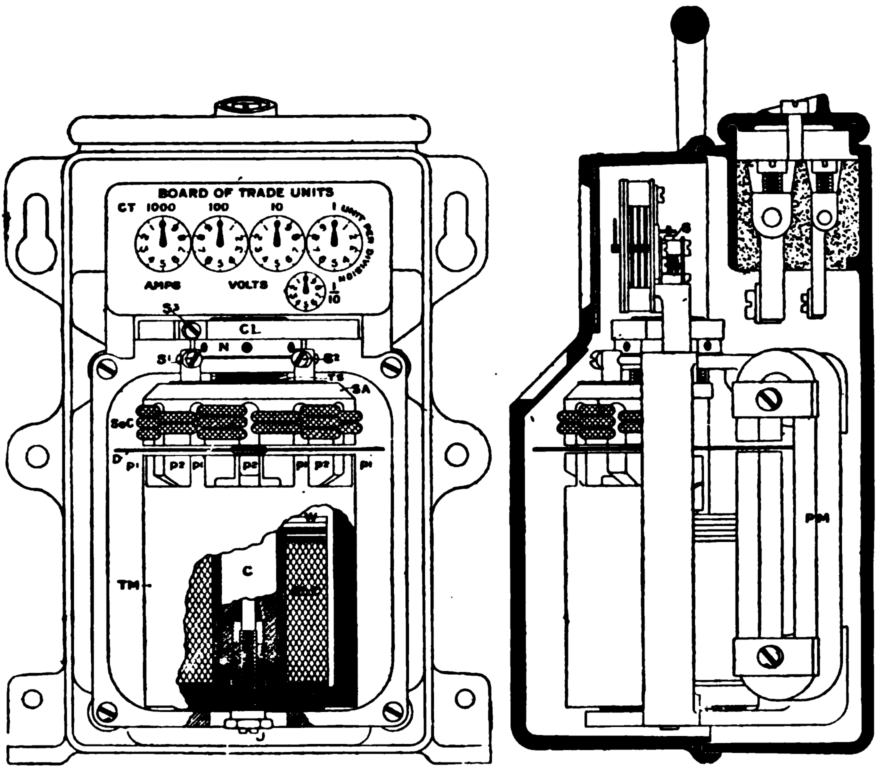

FIG. 152.

The series coils SeC are wound in the slots of a slotted armature S A, which is adjustably mounted above the disc and is fixed by a strong clamp CL and the screws S_1, S_2, and S_3.

The wave form of winding of the series coil is illustrated in Fig. 154, and is similar to that adopted in the Ferranti alternator of 1884. The shunt and series magnets are slightly unsymmetrically placed in relation to one another, the slots of the series armature not being exactly above the poles of the tubular magnet. The object is to obtain a slight torque on the shunt alone, so as to compensate for

FIG. 153.

the friction of the index train and bearings, and for any want of symmetry in the magnetic circuits.

The friction compensation on light loads is easily effected by turning the series armature about the axis of rotation of the disc by means of the two screws S_1 and S_2. If the series magnet be displaced clockwise the disc will tend to revolve in the opposite direction, and turning the series magnet counter-clockwise will tend to produce a clockwise rotation of the disc. With the maximum possible displacement of the series armature the torque obtained is small when the shunt only is energised, so that the tendency to creep is remote. The speed at full load is also readily adjusted by decreasing or increasing the distance of the series armature above the disc by means of the nut N (Fig. 152). This action strengthens or weakens the fields, and when the adjustment has been accomplished the series magnet is firmly clamped by CL and the screw S_3. To facilitate checking, a standard speed of 40 revolutions per minute at full load is adopted, irrespective of the capacity of the meter.

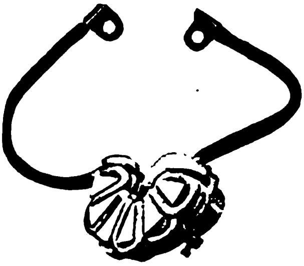

FIG. 154.

The Fort Wayne Single-phase Induction Meters.—In Fig. 155 are shown front and side views of the induction meter, type K, manufactured by the Fort Wayne Electric Works, Fort Wayne, Indiana, U.S.A. The revolving element consists of a light steel shaft, which carries, by means of ribbed arms, an aluminium armature cylinder. It rotates between the poles of the

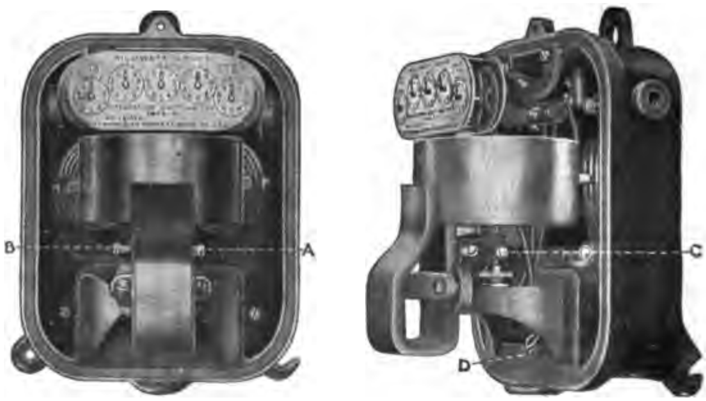

FIG. 155.

permanent magnet, held in position on the front of the lower bracket by a brass clamp. The magnet is adjustable vertically for varying the drag on the aluminium armature, and, from its upright position and distance from the series coils, is shielded from the disturbing effects of excessive currents. The driving torque is exerted on the aluminium cylinder by two series coils and a shunt electro-magnet. The series coils contain no iron, and are clamped to brass spiders mounted on the back of the base of the meter. They are arranged on the outside of the cylinder, and are symmetrically placed as

regards the shunt magnet. The latter consists of a rectangular laminated magnet with a vertical air-gap in which the cylinder rotates, and on its upper horizontal limb it carries the potential coil in series with an impedance coil, which is in the base of the instrument.

The internal connections of the meter are shown in Fig. 156. C and C′ are the two main current coils, D is the shunt coil on the shunt magnet, and I is the impedance coil. The coil G is wound on the light load adjusting arm situated within the opening in the shunt coil D, and is shunted through the 140 cycle lagging resistance H across a few turns of the impedance coil I. By properly adjusting the resistance H, the resultant shunt flux will be brought into quadrature with the main current flux, when the current and

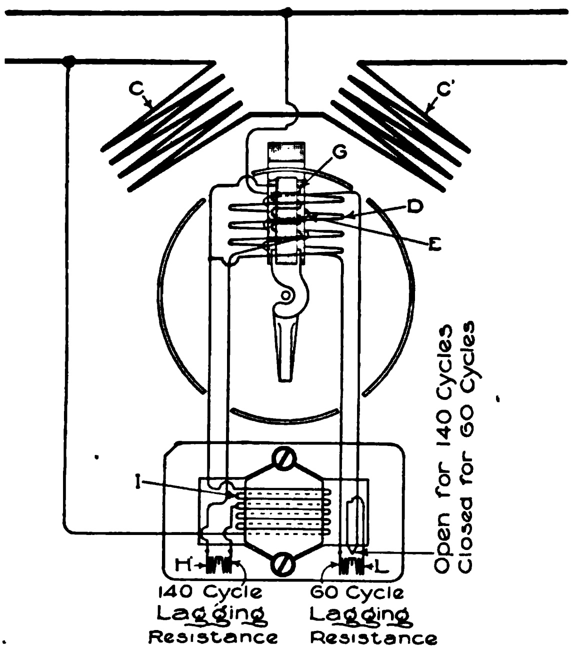

FIG. 156.

E.M.F. are in phase. This constitutes the lagging compensation when the meter is intended for use on a frequency of 140 cycles per second. The meter is, however, double lagged, and when operating on a 60-cycle circuit the above phase conditions become modified. To again obtain the quarter-period displacement between the two fluxes, a coil E (Fig. 156) is wound upon the core of the shunt magnet, and is short-circuited through the adjustable 60-cycle lagging resistance L. The change from a high frequency of 140 cycles per second to the frequency of 60 or 50 cycles per second is effected by soldering together the large copper wires at D (Fig. 155) of this secondary winding, and these ends must be unsoldered and separated when changing back to a high frequency. In general it will be found necessary to correct the speed of the meter, after making this change, by adjusting the position of the permanent magnet.

The meter is provided with a light-load adjustment, which consists of the coil G mounted on the small laminated iron core within the shunt coil. The iron core is attached to a pivoted arm, which can be displaced relatively to the centre of the shunt coil. In the central position the iron core with the coil produces no effect as regards any tendency to drive the disc one way or the other, but if displaced it exerts a slight torque, either retarding or assisting the driving torque on the cylinder. The position of the starting coil is adjusted by means of the screws A and B, and during this adjustment the clamping screw C must not be altered. The screw C provides a means for regulating the friction of the adjusting bracket arm. It is adjusted in the factory so as to produce just sufficient friction to hold the bracket in place.

This company have also recently introduced a new induction meter, type W, illustrated in Fig. 157. In this case the rotating element is a small light aluminium disc, mounted on a short shaft. The permanent magnet in the front is gauge-adjusted. It is attached to the lower bearing bracket by two screws engaging in slotted lugs on the magnet clamp, and its position relatively to the disc is adjusted by a sliding gauge, which can be locked. After the gauge has been set the magnet can be removed, and replaced without further adjustment.

FIG. 157.

Two shunt coils, mounted on the upper and lower arms of the shunt electro-magnet, and two series coils are used to drive the disc, the series coils being situated opposite the shunt coils.

No choking coil is used in the pressure circuit. The 140-cycle meter has a double lagging connection, so that it can be adjusted for a frequency of 140 or 60 cycles per second. The phase compensation is similar to that employed in their type K. The light load adjustment is made by altering the position of a conducting plate in the air-gap, relatively to the revolving disc, by means of a micrometer screw in connection with a guide bar, which is locked by a small set screw when the adjustment has been completed.

The Thomson High-torque Induction Meter.—In the Thomson high-torque induction meter, manufactured by the General Electric Company, Schenectady, N.Y., the phase displacement between the shunt flux and the applied pressure is also made by the employment of a closed secondary winding on the inner pole of the shunt magnet. The arrangement of the electrical system, producing the driving torque on the aluminium disc, is shown diagrammatically in Fig. 158. The shunt coil is wound on the central limb of the shunt magnet, and the two series coils are carried on the two

poles of the lower series electro-magnet, the armature disc revolving in the horizontal air-gap between the two magnetic systems. The secondary winding is used for the phase adjustment. The work done on the disc is absorbed in the adjustably mounted permanent magnets in the front of the meter (Fig. 159), and the registration is effected on the meter dial in the usual manner. The light load adjustment consists in moving backward or forward a small rectangular conductor over the meter disc by means of a lever. Any demagnetising action on the permanent magnets is prevented by their position, which is at right angles to and at a large distance from the coils; moreover, the magnetic circuit of the driving combination is practically closed on itself.

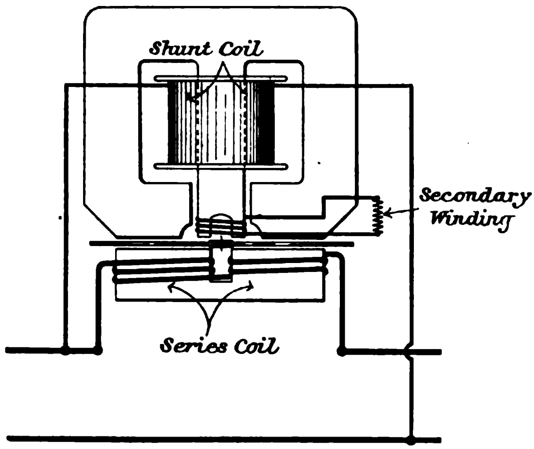

FIG. 158.

This meter, in common with most American meters, is provided with a double lagging arrangement, so that a high frequency meter for 125 and 133 cycles per second can be adapted for use on a 60-cycle circuit. The 60-cycle meter is, however, not provided with this device. An important feature of this meter is, that it can be used without a current transformer for currents up to 300 amperes in a two-wire and 150 amperes in a three-wire system.

FIG. 159.

Scheeffer Induction Watt-hour Meter. — In the meter made by the Packard Electric Company, Limited, Ontario, Canada (the Bastian Meter Co., Ltd., London), the quarter-phase displacement between the shunt and series fluxes, on non-inductive loads, is obtained by means of a choking coil in series with the shunt coils, and a secondary circuit consisting of a few turns of wire wound on the shunt magnet and short-circuited on themselves through a small adjustable resistance. The

general appearance of the meter will be seen in the view given in Fig. 160. The various elements of the meter, except the series coil, are mounted on a frame which is supported in the cast-iron case, and can be easily removed from the latter.

The two shunt coils are carried on the two vertical limbs of the laminated shunt magnet, and are in series with the choking coil situated at the top of the meter behind the registering dials. A pivoted laminated iron bridge, separated from the poles of the shunt magnet by the horizontal air-gap, within which the aluminium disc revolves, completes the magnetic circuit of the shunt field. Above the disc and between the pole-pieces is the series winding, which contains no iron, and the plane of which is perpendicular to that of the shunt coils. The disc is mounted on a vertical spindle, which rests on a highly polished ball in the jewelled step-bearing. It also rotates between the poles of a permanent magnet in the front of the meter, held in a brass clamp capable of motion along two rods at right angle to the supporting frame. The adjustment of the brake magnet is very easily performed. The speed of the meter is altered by loosening the hexagon head screw in the clamp and adjusting a second screw under the same. If this screw be turned clockwise, the magnet will move inwards and the speed of the disc will be decreased; if the meter be running slow, the magnet is moved outwards by turning the screw counter-clockwise.

FIG. 160.

The pivoted laminated iron bridge has attached to it a small lever on the right, which, if moved down, will cause the disc to tend to move forward on the shunt alone, and raising the lever produces a tendency to move backwards, so as to increase or decrease the facility with which the meter starts on low loads. When the friction compensation has been regulated, the position of the bridge is secured by means of a clamping screw in the meter frame.

Stanley Induction Meters.—The magnetic suspension watt-hour meter for alternating currents, manufactured by the Stanley Instrument Company, Great Barrington, Mass., U.S.A., embodies several important features in its electrical and mechanical design, in virtue of which the various disturbing forces inherent to meters of this class are counterbalanced or removed, and the accuracy of the meter will, under normal conditions, remain unaltered. Two illustrations of this meter are given in Figs. 161 and 162, of which the former is a perspective side view of the switchboard instrument, and the latter is a front view of the house-service type.

By means of the magnetic suspension the revolving element floats entirely in the air, and bearing friction, with the consequent jewel and spindle renewals, is entirely eliminated, as no rubbing contact exists between the rotating part and the bearings.

The magnetic suspension is illustrated and explained in detail in Chapter XIII.

A double motor system is used to produce the driving torque, and is symmetrically arranged, one half above and the other half below the armature disc, which is placed midway between the two shunt magnets at a point of zero magnetic potential. In this manner the hammering, which would otherwise ensue, is prevented. In a meter in which the shunt and

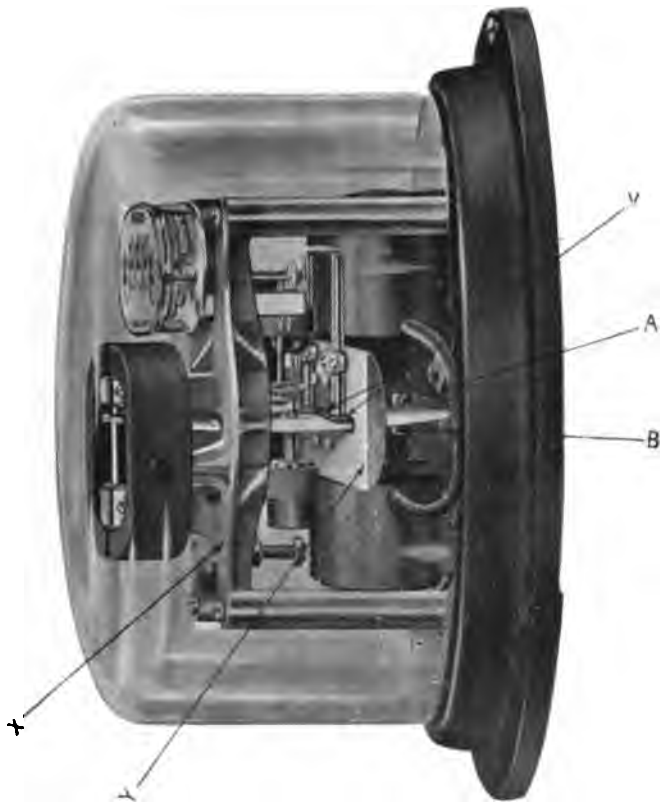

FIG. 161.

series magnets are arranged on one side only of the disc, either above or below it, the latter is made to chatter and pound the jewel-bearings, due to the attractions and repulsions between the magnets and the eddies induced in the disc. These attractions and repulsions are due to the eddies being displaced in phase by more than 90 degrees from the alternating fields producing them. Fig. 163 is a diagrammatic sketch of the shunt and series system, also of the lag compensation employed in the Stanley meters. Two shunt magnets M_1 and M_2 are used, and the armature disc revolves in the horizontal air-gap midway between them. Each shunt magnet has two energising coils, making four in all, connected together in series across the supply

mains. The series winding contains no iron and is made in two halves A and B, which are placed the one above and the other below the horizontal air-gap between the poles of the shunt magnets.

C_1 and C_2 are the magnetic bridges extending across and between the shunt magnets, by means of which and the self-induction of the shunt coils exact quadrature is obtained between the shunt and series fluxes when the main current is in phase with the supply voltage. The parts are so designed—that is, the air-gaps, conductivity of the magnetic bridges, etc.—that an external adjustment is unnecessary, and the meters register accurately on inductive loads of any power factor.

These magnetic bridges are composed of sheet-iron plates built up to the

FIG. 162.

necessary thickness. Each presents an auxiliary path for the passage of a certain amount of the magnetic lines produced by the shunt system, depending upon the air-gaps at each end and the air-gap in which the disc revolves; in other words, it is the ratio of these two air-gaps which determines the amount of flux which passes over this magnetic bridge. The eddy currents set up in the revolving disc reacting, cause, in their turn, a certain flow also back and across the magnetic bridge. The combined interaction is sufficient and of such a nature to produce quadrature between the shunt and series fluxes with a load of unity power factor, and, consequently, the meter registers correctly on inductive loads. The construction, as indicated in the diagram (Fig. 163), is true only for a given thickness of rotating disc, *i.e.* for a disc of given conductivity. Any change in this conductivity will change the

reaction from the disc on the shunt system and cause some angle of lag other than 90 degrees.

The vector diagram of the meter is given in Fig. 164. O E represents the applied pressure of the supply circuit and O S the resulting shunt current, lagging behind the pressure by about 80 degrees, as also the flux O F_1 to

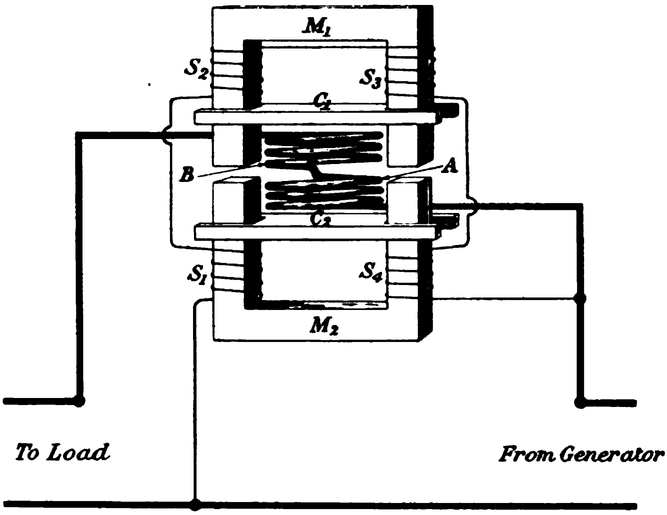

FIG. 163.

which it gives rise. O F_2 is the flux due to the eddies induced in the magnetic bridges displaced by more than 90 degrees from O S. These two fields, when properly adjusted, combine in the horizontal air-gap to a resultant flux O F at right angles to the impressed voltage O E, or to the series flux O F′ produced by a main current O M in phase with the supply pressure.

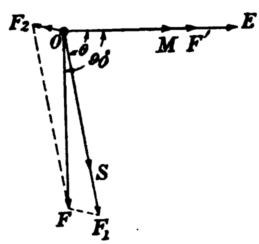

FIG. 164.

In the meters made by this company the side thrust exerted on the bearings by the unsymmetrical field is completely counterbalanced. In an induction meter in which the motor system is not placed centrally with reference to the disc, but close to one edge, the field produced by the eddies induced on the disc is crowded in from the side towards the edge.

The unsymmetrical field tends to displace or tilt the disc out of its normal position, producing a side thrust on the bearings. This side thrust is nullified by the use of a short-circuited winding. In the case of most of their meters it consists of a mere copper band around one-half of the shunt pole, as can be seen at A and B, Fig. 161.

This copper band produces an unsymmetrical field in the shunt core, or, rather, two fields of slightly different time constants are produced, which, with the band located on the back half of the core, tend to throw the disc back into its normal position, and by properly adjusting the winding of this band the force due to the unsymmetrical field in the disc is counteracted.

At V, Fig. 161, will be seen small copper vanes which are swung underneath the shunt pole for the purpose of balancing the meter on the shunt only, so as to counteract the effect of creeping.

The dial and brake magnets are mounted on the front of the supporting frame, Figs. 161 and 162, and the brake magnets are protected from the motor system by an iron shield marked Y in Fig. 161.

Two permanent magnets are used with soft iron pole-pieces between their

FIG. 165.

poles, and containing a gap in which the disc revolves. The braking effect is adjusted by raising or lowering the screw under the lower brake pole, decreasing or increasing the gap as desired.

The magnets themselves are fixed in position and the brake field is unaffected by ordinary external influences, as the soft iron pole-pieces are always highly magnetised.

Fig. 165 is a front view, with the cover removed, of the jewel meter, type H, made by this company. The main difference between it and the

magnetic suspension meter is that the meter shaft is supported in a jewel spring-bearing. The same electrical design is used in this type, and the side thrust, creeping, and disc vibration are balanced in exactly the same manner.

The meter is designed mainly for small installations, taking up to about 15 amperes for two- and three-wire circuits.

The motor part is enclosed in an iron box forming the back portion of the meter case, separated from the front by a division plate which also constitutes a magnetic shield.

The air-gap of the brake magnet can only be changed by means of the adjusting screws placed on the yoke below the disc, and in this way the speed of the meter adjusted. The position of the brake magnet is itself invariable.

FIG. 166.

A new meter, of the jewel-bearing type, illustrated in Fig. 166, has just lately been put on the market by this company, and is known as the Stanley rotated jewel-bearing induction meter. It has practically the same motor construction as in the type H, Fig. 165, the novelty being in the jewel-bearing, a description of which is included in Chapter XIII. This meter can also be very quickly and easily adjusted for any frequency from 40 cycles to 133 cycles per second. This is accomplished by the magnetic shunt principle used in the Stanley meters. A contact on a small rheostat is moved, which alters the reluctance of the magnetic circuit, so that the shunt system can be adapted to the different frequencies. The ratio of the torque to the weight of the disc is 10 to 7, the torque being 50 millimetre-grammes, the weight 35 grammes, and the shunt loss is 1 watt at 110 volts. Creeping is prevented by means of one of two balancing vanes on each side of the revolving disc, and either can be brought between the disc and the shunt pole below it.

The A.C.T. Induction Watt-hour Meter of the British Thomson-Houston Company, for inductive and non-inductive loads, is of very simple electrical and mechanical design. It is typical of the third class of induction meters, in which the phase difference of a quarter period is obtained between the main current and pressure current fluxes, when the currents and E.M.F. are in phase, by creating a large phase-shift between the shunt flux and the pressure, and splitting up the main current into two branch circuits in the meter, of

which the one is practically free from self-induction, whereas the other is made highly inductive, so that the resultant series flux leads in advance of the pressure, and the angle of lead will be exactly the complement of the angle of lag of the pressure circuit when the meter has been properly adjusted.

In Figs. 167 and 168 are two illustrations of the meter, which show its general appearance with and without the cover. It is very compact, and is perhaps the smallest meter in use, having an overall length of but 8 inches, and being slightly more than 5 inches in width.

One shunt electro-magnet and two main current electro-magnets comprise the driving elements of the meter. The two main current coils, one on each of the two magnets, are connected in parallel with one another, and in series with one of them is a variable resistance for the phase adjustment. The resulting shunt and main current fluxes act upon a pivoted copper disc, and rotate it with a turning moment proportional to the power expended in the circuit (*i.e.* E.C. cos ϕ). A permanent magnet operates upon the same disc and provides the retarding torque proportional to the speed.

FIG. 167.

The dials record direct the units consumed, and are driven in the usual manner.

All the parts are readily accessible, the different adjustments can be altered, and the whole meter taken to pieces, if necessary, with speed and ease.

A light frame fixed to the meter base supports on its front face the integrating train and retarding magnet, and carries at its lower extremity the jewel screw-bearing. These parts of the meter, together with the disc and the adjustable resistance with its sliding contact, are clearly visible in Fig. 168. On the back of the frame are mounted the shunt and series systems. The electrical elements of the meter and their relative arrangements are shown diagrammatically in Fig. 169, the friction compensation device being omitted for the sake of clearness.

N is the shunt magnet, composed of soft iron stampings. It is energised by the pressure coil, and has an almost closed iron circuit, except for the small vertical air-gap V. Its lower pole-pieces are extended and carry the bobbin on which the one main current coil H is wound. Immediately below the shunt magnet, and separated from it by the horizontal air-gap in which the armature disc R rotates, is a second small laminated magnet. It consists

practically of two horseshoe magnets, with their vertical yokes combined to form a middle limb on which is wound the second main current coil H′.

In series with the upper coil H is the adjustable resistance W, made of constantan, or German silver wire, part of which can be short-circuited by the sliding contact X. H′ is wound in the opposite sense to H, and the two are connected in parallel as shown in the diagram.

The principle of the meter will be readily understood by reference to the vector diagram, Fig. 170, and consists essentially in the utilisation of the fluxes produced by the main current and pressure current coils. Each of the two fluxes, *i.e.* the shunt flux and the resultant series flux, induces eddy currents in the disc, the rotation of which results from the mutual interaction of the main current magnet on the Foucault currents generated by the pressure coil, together with the interaction between the eddy currents induced by the main current coils with the shunt magnet.

FIG. 168.

E denotes the P.D. of the supply circuit, and C is the main current flowing, supposed in phase with E. S is the shunt current, and gives rise to the flux F_S, both of which, owing to the large self-induction of the pressure coil, lag considerably behind the voltage of the circuit by an angle ϕ, less than 90 degrees. Most of the lines of force, due to the pressure current S, flow in the shunt magnet direct through the vertical gap as in a continuous ring, and only a small percentage of them cuts the disc.

The main current C, in phase with E, divides into two portions in the meter, the one part traversing the winding H′ on the lower magnet, and the other flowing round the coil H on the upper magnet poles. The coil H has a low self-induction compared with its ohmic resistance, so that the greater part of the current circulates in it, and it would, if acting alone, tend to drive the disc in the direction of rotation.

The current C_b in this branch, and also the flux F_1 to which it gives rise, lead in advance of the total current C by a small angle ϕ_2. The winding H′ has, relatively to H, considerably more self-induction, and is traversed by a weak current only; moreover, it is wound in the opposite sense, and this results in displacing its magnetic flux through 180 degrees relatively to the current in it. This current C_a lags behind the main current in the circuit by an angle ϕ_1, and the flux F_2, which it produces, differing from it in phase by 180 degrees, will be in advance of the total current C. The two fluxes F_1 and F_2 combine to a resultant flux F_R, which leads by a small angle ahead of the main current C in the circuit.

When the meter is properly adjusted, F_R should be at right angles to F_S, and the meter will then read correctly on any power factor.

A second vector diagram of the meter is shown in Fig. 171, to illustrate the

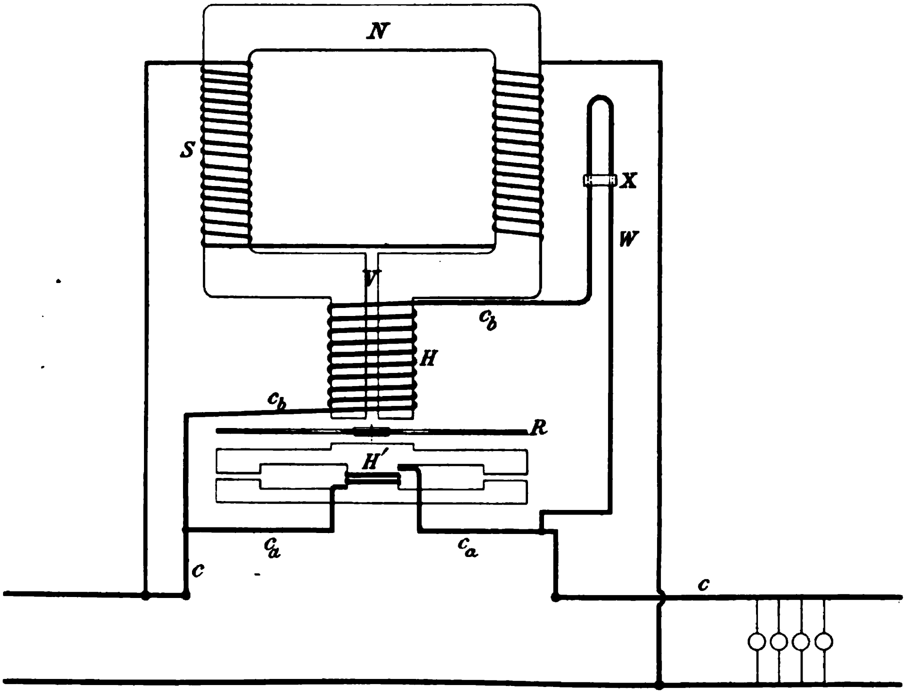

FIG. 169.

case in which the current C lags behind the pressure E by some angle ψ. To draw the diagram it is only necessary to first assume the current in phase

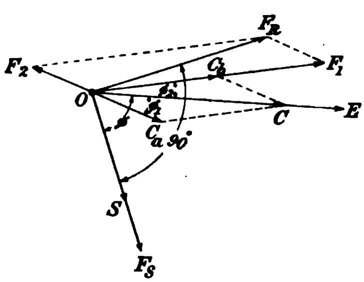

FIG. 170.

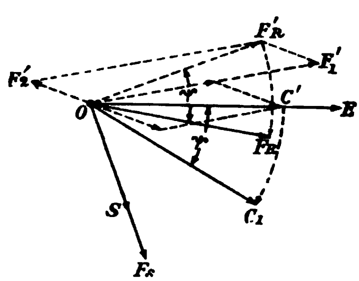

FIG. 171.

with the E.M.F. The current is then shown as at C′, and the resultant series flux F'_R is at right angles to F_S, as explained above. The current vector is then rotated through the angle of lag ψ into its correct position as at C_1. Now, the currents in the two current windings will not be altered relatively to

one another, on account of the main current being out of phase with the E.M.F., but only their relationship, *i.e.* angular displacement, with respect to the pressure. The effect is, therefore, to simply turn the resultant series flux through an angle ψ, and the vector F'_R is drawn in the position F_R such that the angle $F'_R O F_R$ is the same as the angle of lag. The torque is proportional to the true power E.C. $\cos\psi$. In every case, if T denote the torque,

$$T \propto F_S . F_R . \sin F_S O F_R .$$

$$\text{Now} \qquad \sin(F_S O F_R) = \sin(F_S O F'_R - F'_R O F_R)$$
$$= \sin(90^\circ - \psi)$$
$$= \cos\psi .$$

$$\text{Also} \quad F_R \propto C \quad \text{and} \quad F_S \propto E ,$$
$$\therefore \qquad T \propto E.C. \cos\psi .$$

In Fig. 172 is given a sketch of the meter for the purpose of explaining

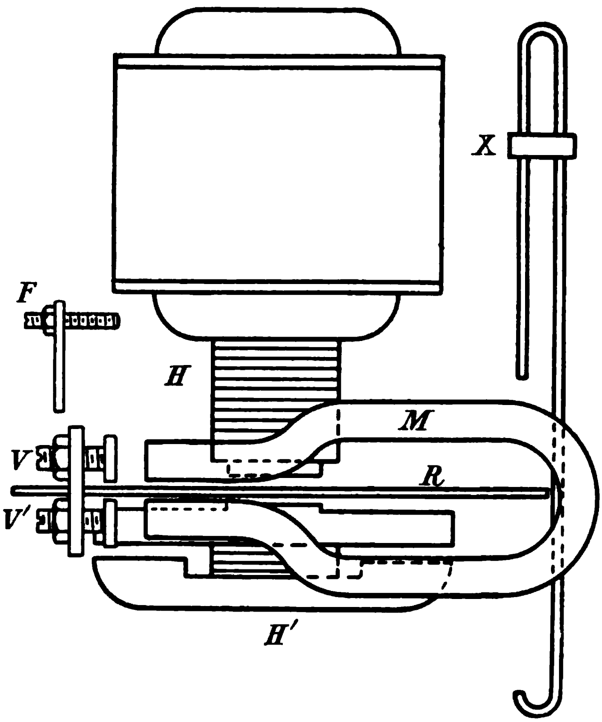

Fig. 172.

the method of carrying out the various adjustments. V and V′ are two iron screws, so mounted that they face the poles of the permanent magnet M, and, according to their position, shunt the flux more or less. When screwed in they shunt more of the flux, and thereby weaken the brake field in which the disc R rotates, with a corresponding increase in the speed of the meter. If

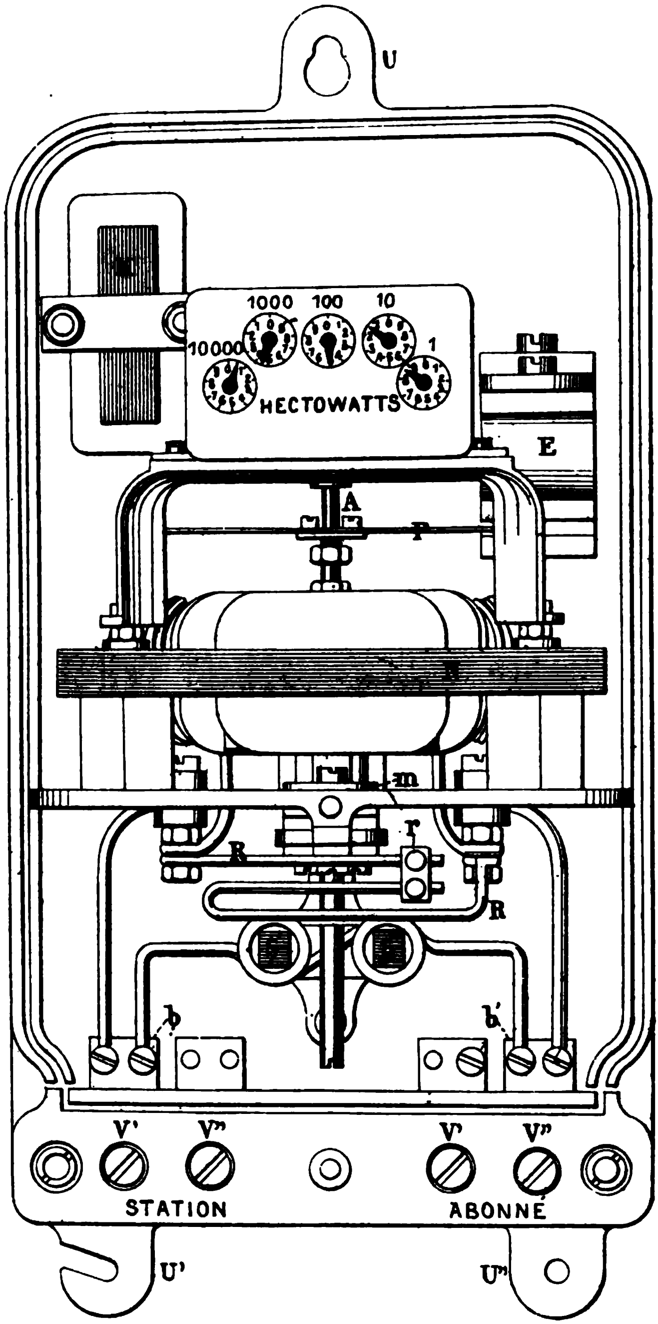
U
1000
100
10
10000
1
HECTOWATTS
E
A
P
m
r
R
R
b
b'
V'
V"
V'
V"
STATION
ABONNÉ
U'
U"

FIG. 173.

the speed be too high, the screws must be screwed out, further away from the poles. This affords a very reliable and easy method of effecting the high load adjustment. The screws are fixed by means of lock nuts when the adjustment has been completed, and the magnet itself is not moved. The friction compensation device, by which the speed of the meter is regulated on low loads, consists of an iron strip and screw shown at F. This strip shades the left-hand pole and produces a shifting field which tends to drive the disc. The intensity of the field is controlled by the iron screw, which, on being screwed in, accelerates the disc.

The phase adjustment for inductive loads has already been explained, and is performed by altering the position of the sliding contact X, which is soldered when the adjustment is made. By altering the position of X the resistance in the circuit H is changed, while that of the circuit H′ remains unaltered. This varies the relative reactance of the two branches. If the resistance in H be increased, ϕ_2 will increase and ϕ_1 will diminish (Fig. 170). X is moved up or down until the resultant series flux is at right angles to the shunt flux, when the meter is correct. This adjustment is usually carried out with a power factor of about ·5 or ·3. The shunt loss is very low, generally less than 0·5 watt, from 100 to 230 volts, with a periodicity of 50 cycles per second. The torque at full load is $3\frac{1}{3}$ centimetre-grammes, and the weight of the revolving element 60 grammes.

Single-phase Induction Meters, Types B.L. and I.R.—The alternating current meter for inductive loads, type B.L., of the Compagnie Anonyme Continentale pour la Fabrication des Compteurs, Paris, is illustrated in Figs. 173 and 174. The requisite quarter-phase displacement between the main and the pressure current fluxes operating the meter, when the main current is in phase with the pressure, is obtained by the employment of a suitable reactance in series with the pressure coils and an inductive shunt to the main windings of the meter, which latter are, further, connected together through an adjustable resistance. The main supply current, on entering the meter, splits up between these two branches. The inductive shunt will only carry a small fraction of the whole current in the circuit, owing to its self-induction, and this current will lag behind the total current, whereas that flowing in the main windings proper of the meter will form the larger part of the total current, and will lead in advance of it.

By suitably adjusting the resistance, which alters the relative reactance of the two main current branches, and also the choking coil in the pressure circuit, the meter should function correctly on inductive loads.

It can be easily shown that the current in the main windings will always be proportional to the total main current flowing in the circuit, whatever the value may be. The object of the choking coil in shunt with the main current coils is to reduce these windings, and to cause the current in them to lead and to produce a leading magnetic field. It will be further noticed that the flux due to the lagging part of the current in the inductive shunt is not used to influence directly the revolving part of the meter.

Referring to the illustrations, an aluminium bell C constitutes the armature of the meter, and is mounted on a steel spindle A, resting on a flexibly carried jewelled bearing. The upper part of the spindle carries both the driving worm actuating the meter dials and the aluminium brake disc P, rotating between the poles of a permanent magnet E. The driving element is composed of a laminated iron ring having three inwardly projecting poles N, N′, N″. The bell C rotates in the air-gap between these poles and the

eccentrically-placed laminated iron core M. The core M serves to concentrate the lines of force and to augment the driving torque. By means of the adjusting arm *m* attached to it, the core can be displaced relatively to the poles and the sensitiveness of the meter adjusted on low loads. The pressure winding consists of three coils mounted on the three poles, as shown in the illustrations. In series with these coils is the adjustable choking coil K, and the pressure circuit is connected direct across the supply mains.

The two main current coils are wound on the poles N and N′, and are connected together by the resistance R, which can be partially short-circuited by the adjustable sliding contact *r*. These coils are connected at their other

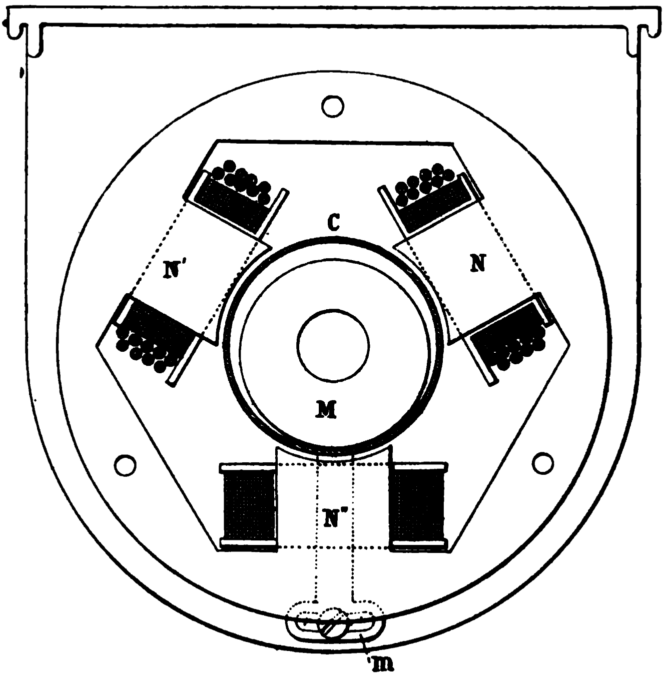

FIG. 174.

ends to the main current terminals *b b′*, which are shunted by the inductive resistance S S.

The speed of the meter at top loads is increased or decreased by altering the position of the brake magnet E, adjustably mounted for this purpose.

A meter suitable for small consumers is also manufactured by this company. A sectional drawing of the instrument, type I.R., is given in Fig. 175, and its action will be understood by reference to Fig. 176. The moving element is a copper bell C mounted in the usual way; it forms at the same time the brake in conjunction with the permanent magnet E. The shunt coil of the meter is wound on the yoke of a laminated iron magnet, the two pole-pieces of which are each provided with three teeth. The copper bell rotates between these pole-pieces and encloses a stationary soft iron core M. The core concentrates the fields produced and forms the light load adjustment

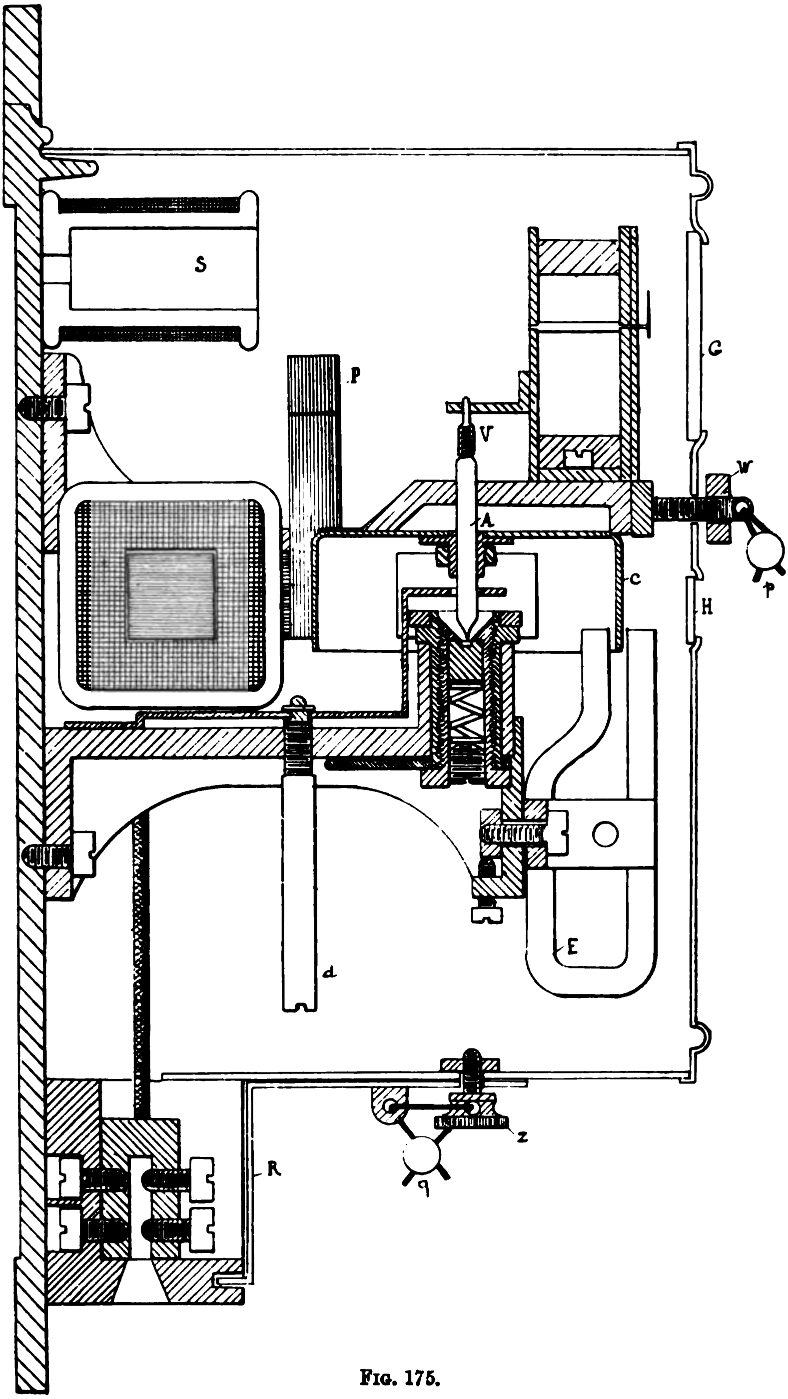

FIG. 175.

device. Its position relatively to the teeth of the poles is altered by rocking the adjusting arm D, which is attached to it and is controlled by means of the two screws V and V′. A very sensitive adjustment can be obtained by this method. The main current coils are distributed in the notches on the pole-pieces, as shown in the diagram, Fig. 176, and are wound in the same sense on the two branches of the magnet. The result is that the fluxes produced by these main current coils oppose each other in the iron core; they, therefore, form local circuits round the windings. A laminated iron bridge-piece P

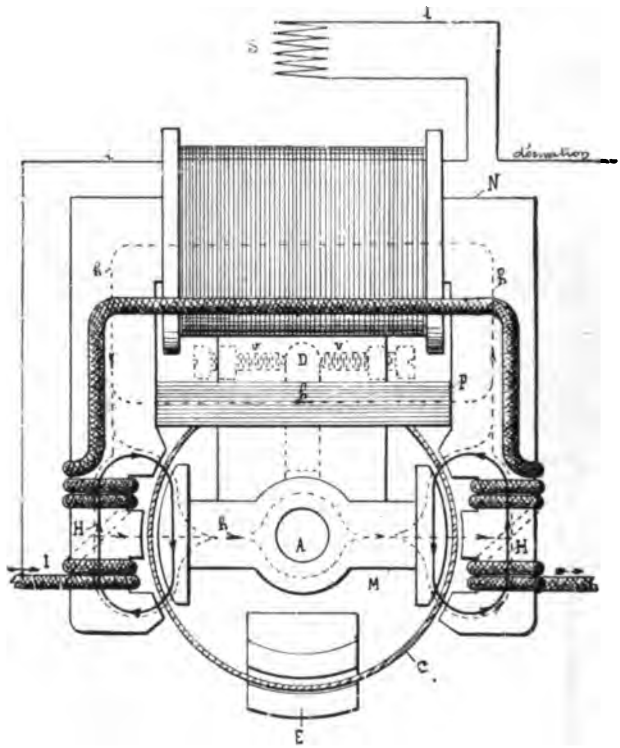

FIG. 176.

short-circuits the two limbs of the magnet and considerably increases the self-induction of the pressure coil connected in series with the choking coil S.

The greater part of the shunt flux h takes the path through the bridge P, and only a small part traverses the core M. This part, together with the magnetic flux H of the main current coils, produces the driving torque.

The shunt flux h and the main current flux H are indicated respectively by the dotted lines and those shown in full in Fig. 176.

Eclipse Meter.—Fig. 177 is a diagram showing the motor system used by the Luxsche Industriewerke, Munich, Germany, in their 'Eclipse' meter, type F.E.G., for non-inductive loads only, such as incandescent lamps. The shunt flux is produced by means of a single pressure coil S wound on the central limb of a three-pole laminated shunt magnet N, constructed as a

choking coil, with an almost closed magnetic circuit. About 90 per cent. of the lines of force form closed loops through the vertical air-gaps V_1 and V_2, and the remaining 10 per cent. cut the revolving disc A and induce the shunt eddies in it.

The lag of the shunt current behind the pressure of the circuit is about 75 degrees, and an auxiliary choking coil is not used for circuits up to 250 volts.

Below the armature disc A and opposite the shunt magnet N is the four-pole series stator, which is energised by two main current coils wound on the two inner poles P_2 and P_3 and placed in series in one of the supply mains. With the polar gaps of the shunt and series magnets displaced relatively to one another, as in the arrangement adopted, the shunt eddies are dissipated in the

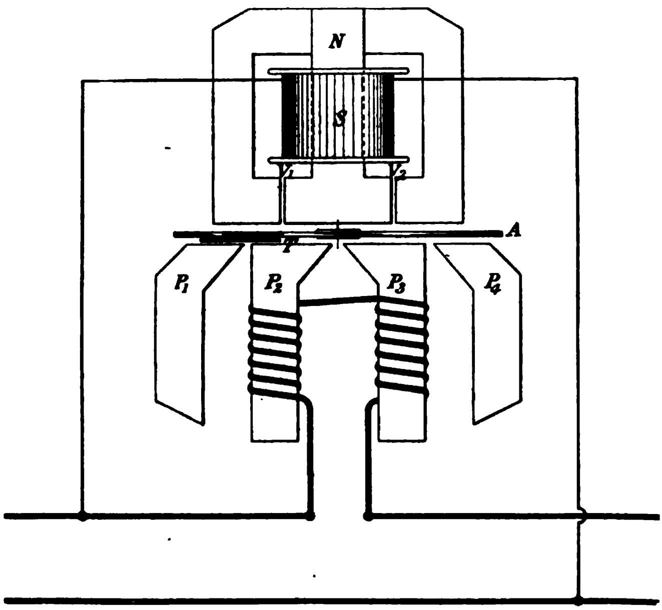

FIG. 177.

main current field and the series eddies in the shunt field, and, in consequence, the torque obtained is fairly high compared with the relatively weak fields used.

For circuits in which the current is out of phase with the voltage, this company use the 'Eclipse' meter, type F.E.M., in which an exact quarter-phase difference is obtained between the shunt and main current fluxes when the power factor is unity.

The method employed is similar to that adopted in the A.C.T. meter, and consists in making the main current flux lead in advance of the main current. The main and series system of the type for inductive loads is illustrated in the diagram in Fig. 178. It differs from Fig. 177 mainly in the series winding, which is composed of four coils wound on the four poles of the series magnet. The main current, supposed in phase with the P.D., divides into two components C_1 and C_2, of which the one, C_1, flows round the two inner poles P_2 and P_3, giving rise to only a few lines of force, which nearly all cut

the disc A. The other component, C_2, flows round the outer poles P_1 and P_4, each of which has an iron short-circuiting piece G, and produces several lines of force, which, however, are for the most part short-circuited on themselves, and only a very few will traverse the disc. The two systems of coils are

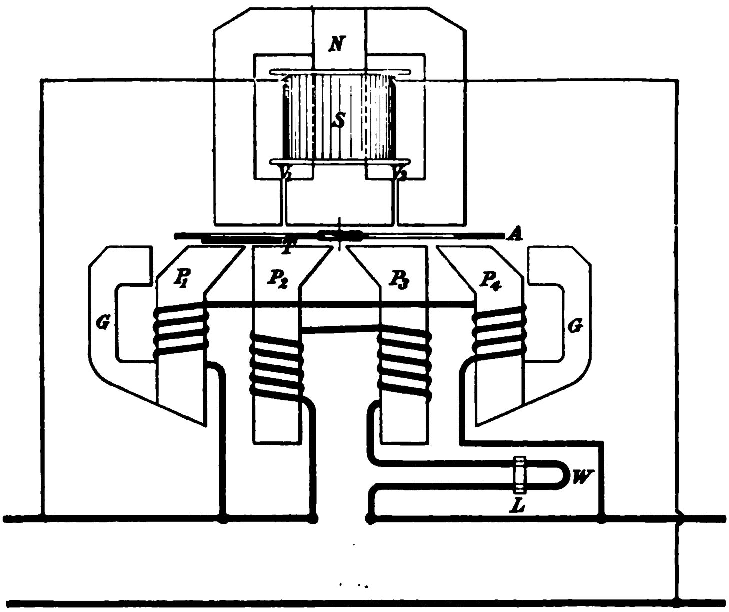

FIG. 178.

placed in parallel, and are wound so as to oppose one another, the coils on the inner poles behaving exactly as in the previous type.

The windings on P_2 and P_3 are connected together in series with an adjustable resistance of nickel wire W, part of which can be short-circuited by means of the sliding contact L. By regulating the resistance W, the relative inductance of the two branch circuits can be altered until the resultant main current flux is at right angles to the shunt flux, when the main current is in phase with the pressure, as in the vector diagram in Fig. 179. O E is the pressure, O F_S is the shunt flux, due to the shunt current O S lagging about 75 degrees behind O E. O C is the main current, supposed in phase with O E,

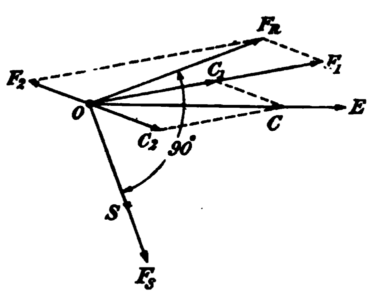

FIG. 179.

O C_1 is the current component round the inner poles P_2 and P_3, producing the flux O F_1, and O C_2 is the component round the outer poles P_1 and P_4, giving rise to the flux O F_2. O F_1 and O F_2 combine to the resultant O F_R at right angles to O F_S. In both types the armature consists of a light aluminium disc mounted on a vertical spindle supported in a jewelled spring-bearing. The

whole revolving system weighed only about 15 grammes, and, in consequence, no clamping device is used. The disc revolutions are conveyed in the usual manner to a counter with springing figures, which indicate the energy consumption direct in units. The brake torque is produced by a permanent magnet, between the poles of which the armature disc rotates. The position of the magnet relatively to the disc can be altered for performing the high load adjustment.

The friction compensation consists of a small iron strip T, adjustably mounted between the armature disc and the series magnet (Figs. 177 and 178). The shunt flux is by this means made unsymmetrical, and an auxiliary starting torque is obtained proportional to the voltage. To prevent running on the shunt alone, a fleck of iron dust is lacquered on the disc. The disc can, under the influence of the shunt alone, only rotate until this spot comes between the poles, when it is held, and further motion is stopped. Fig. 180 is a front view of the type F.E.M., for inductive loads. The motor system is fixed to the back of the case, and the front supports the brake magnet, the counter, and the bearings, the disc partially projecting through the base into the back of the meter, which is closed by a zinc cover. In external appearance the two meters do not differ. With the arrangement of the current-carrying parts on one side and the brake system on the other side of the base, the latter acts as a complete magnetic shield to the magnet.

FIG. 180.

Meters with Current and Pressure Transformers.—In a low-tension 200 volt system, when the current exceeds 50 to 100 amperes, alternating current meters are used in connection with series or current transformers. The main current flows through the primary ampere-turns of the transformer, the secondary ampere-turns of which are connected to the main current terminals of a small capacity meter. The size of the transformer naturally depends upon the total current of the circuit, whereas the meter is, in general, wound for a standard maximum current of about 5 or 10 amperes, the actual capacity of the meter varying in the different types.

The transformers are so designed that they give a constant ratio over the entire range, from the lightest load to a large overload. On inductive loads a series transformer, according to its design, will cause the meter to run either slightly too fast or too slow, and, therefore, meters to be used with current transformers are either under-compensated or over-compensated, so that they are somewhat slow or fast on inductive loads without the transformer, and are correct on all loads when the transformer is used.

For high-tension systems, both pressure and current transformers are used, whatever the current capacity of the circuit, so that no high-tension current traverses any part of the meter, which can, therefore, be handled with impunity. The shunt circuit of the meter is placed in series with the low-voltage secondary of the potential transformer, the primary terminals of which are connected across the high-tension mains, and the main current coils of the meter are connected to the series transformer, as already explained.

In Fig. 181 is a diagram of connections of a Westinghouse meter, to

illustrate the case in which both a pressure and a current transformer are used on a high-tension single-phase circuit.

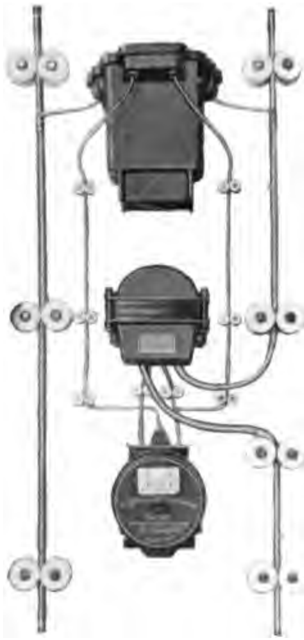

Fig. 181.

For voltages below 600 or 500 volts, but above 250 volts, some firms employ potential ratio coils and choking coils instead of transformers, using, however, the latter for higher pressures. The potential ratio coil is connected direct across the circuit, and a point in it is joined to the shunt terminal of the meter, so that the voltage across the pressure circuit of the latter is reduced to about 100 or 110 volts. When the capacity of the circuit exceeds about 100 amperes, in addition to the potential ratio coil, a current transformer is used. A diagram of connections of a Stanley meter with a potential ratio coil, on a 600-volt single-phase, small capacity circuit, is given in Fig. 182, as typical of this method. When a choking coil is used, the pressure circuit of the meter is placed in series with the choking coil direct across the supply mains.

Switchboard induction meters present no special features. They simply consist of the usual types, suitably mounted for fixing on a switchboard, and they are enclosed in cylindrical, metal or glass cases. They are used in connection with both pressure and current transformers, each meter having its own series transformer, but only one or two pressure transformers are used to

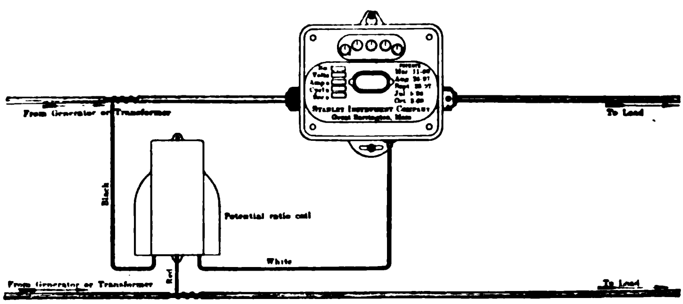

Fig. 182.

energise the low-tension instrument bus-bars, to which the shunts of the meters are connected.

CHAPTER IX.

POLYPHASE METERS.

Two-Wattmeter Method of Measuring Power—General Description of Polyphase Meter—Polyphase Meters for a Three-phase Four-wire System—Behaviour of Three-phase Three-wire Induction Meters on Inductive Loads—Condition for Use of One Single-phase Induction Meter—Effect of Wrongly Connecting a Three-phase Three-wire Meter—Aron Polyphase Meters—Bat Polyphase Meters—Electrical Company's Three-phase Meter—Three-phase A.C.T. Meter—Deutsch-Russische Three-phase Meter—Fort Wayne Polyphase Meter—Siemens-Schuckert Polyphase Meters—Thomson Polyphase Meter—Westinghouse Polyphase Meter.

Two-Wattmeter Method of Measuring Power.—The mathematical principles involved in the measurement of the electrical power absorbed and, consequently, the electrical energy consumed in a given time in a polyphase system, have been explained in Chapter VII. By a polyphase system is meant a two- or three-phase network with three and four conductors.

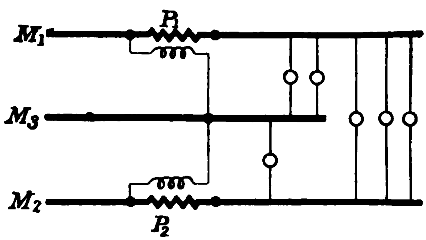

FIG. 183.

The general method of measuring the power absorbed in a two-phase three- or four-wire system, and in a three-phase system with three conductors, consists in the use of two wattmeters, connected as shown in Fig. 183, which represents a three-phase three-wire network, both for a star or delta coupling of the three-phase branches.

The instantaneous value of the power is

$$p = v'_1 . c_1 - v'_2 . c_2 .$$

The mean power is

$$\mathrm{P} = \frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} v'_1 . c_1 . dt - \frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} v'_2 . c_2 . dt ,$$

where v'_1, v'_2, v'_3 and c_1, c_2, c_3 are the instantaneous values of the pressures between the supply mains and the currents in those mains. P_1 and P_2 are the two wattmeters, and the method is commonly known as the two-wattmeter method of measuring power. It follows that two induction watt-hour meters connected as in Fig. 183 will measure the energy consumed in such a

circuit whether balanced or unbalanced, P_1 and P_2 now representing energy meters.

In a three-phase star- or delta-coupled system, when the load is equally distributed between the three-phase circuits, the equation for the mean power was shown to reduce to

$$P = \sqrt{3}.V.C. \cos(\phi - 30^\circ) + \sqrt{3}.V.C. \cos(\phi + 30^\circ),$$

where V and C are the phase pressure and the phase current (or main current) for a star coupling, and for a delta connection V is the P.D. between the mains, and C is the phase current in a leg of the triangle, all being root mean square values; also ϕ is the angle of lag, which in this case, as the system is balanced, is the same for each phase.

If V_1 denote the P.D. between any two of the supply mains, and C_1 the current flowing in one of the mains (R.M.S. values), then for a star coupling

$$V_1 = \sqrt{3}.V \quad \text{and} \quad C_1 = C,$$

and for a delta coupling

$$V_1 = V, \quad \text{but} \quad C_1 = \sqrt{3}.C,$$

so that in both cases the mean power is

$$P = V_1C_1 \cos(\phi - 30^\circ) + V_1C_1 \cos(\phi + 30^\circ).$$

The energy consumption in the time $(T_2 - T_1)$ is, therefore,

$$E = \int_{T_1}^{T_2} V_1C_1 \cos(\phi - 30^\circ)dt + \int_{T_1}^{T_2} V_1.C_1 \cos(\phi + 30^\circ)dt.$$

The one induction watt-hour meter reads $\int_{T_1}^{T_2} V_1C_1 \cos(\phi - 30^\circ)dt$ and the other $\int_{T_1}^{T_2} V_1.C_1. \cos(\phi + 30^\circ)dt$, the sum of the two readings giving the total three-phase energy consumption, viz. $\int_{T_1}^{T_2} \sqrt{3}.V_1.C_1 \cos\phi dt$.

When the currents and pressures are in phase, *i.e.* $\cos\phi = 1$, then

$$E = \int_{T_1}^{T_2} V_1C_1\frac{\sqrt{3}}{2}dt + \int_{T_1}^{T_2} V_1.C_1 \frac{\sqrt{3}}{2}dt = 2\int_{T_1}^{T_2} V_1.C_1 \frac{\sqrt{3}}{2}dt.$$

Each meter reads $\int_{T_1}^{T_2} V_1C_1 \frac{\sqrt{3}}{2}dt$, so that the total energy consumed is, in this case, obtained by using a single ordinary induction meter suitable for a two-wire single-phase alternating current circuit, connected as P_1 or P_2 (Fig. 183), and by doubling the difference between its two readings taken at the commencement and termination of the interval under consideration.

In general, when a single-phase meter is intended for use on a perfectly balanced three-phase system with a power factor of unity, the integrating mechanism is so geared that the readings give the total energy taken, and it is then not necessary to use the multiplier 2.

When the system is unbalanced, and also when the system is balanced, but the currents and pressures are not in phase (*i.e.* cos $\phi \neq 1$), then two watt-hour meters must be used. By suitably choosing the constants of the two meters they can be combined to form one instrument, and this is the general method adopted.

General Description of Polyphase Meter.—A polyphase meter, therefore, consists, in general, of a combination of two single-phase motor-meter elements operating upon one armature disc, or cylinder, or upon two such revolving parts, in which case the two armatures are mounted on a common spindle. The revolutions of the meter spindle in either case are transferred to an integrating train in the usual manner, and the ordinary magnetic brake system is used. The total torque exerted on the meter spindle is the algebraic sum of the torques exerted by the two motor elements, and is proportional to the total polyphase power, so that the difference between two readings of the meter dial gives the total polyphase energy consumed in a given interval. The polyphase meter for unbalanced loads is usually connected to the two-phase or three-phase circuit in the same manner as when two watt-meters are used for measuring power (Fig. 183). This, however, does not apply to polyphase meters for measuring the energy consumed in a three-phase system with four conductors.

By the adoption of a single instrument to measure the energy, however unbalanced the phase circuits may be, large economy is secured. The usual method consisted in the employment of two independent single-phase watt-hour meters. The use of two separate meters has, however, several disadvantages. The capital cost is increased, the maintenance charges and the erection costs are duplicated. Space has to be provided for two meters instead of one, and two meter readings have to be taken and added together, with the result that errors can easily be introduced.

In an induction meter for ordinary single-phase circuits it has been pointed out in previous chapters that the pressure current and main current fluxes operating together on the revolvable disc must have a phase displacement of one-quarter period relative to one another when the current and the E.M.F. are in phase, *i.e.* when the meter is operating on a purely non-inductive load. Exactly the same condition must be fulfilled by each of the motor systems of the polyphase meter, whether for balanced or unequally loaded systems.

By so choosing the pressures of the three-phase system to produce the shunt fields, special artificial phase devices need not be employed, on the assumption that the pressures of the three-phase system are equal to one another and have a relative phase displacement of 120 degrees. In the Siemens-Schuckert three-phase meter, type F.U., this method is used.

As with single-phase meters, current and pressure transformers are used for the measurement of heavy currents and high voltages, and on high-tension systems both current and pressure transformers are employed, whatever the capacity of the installation.

Polyphase Meters for a Three-phase Four-wire System.—In a three-phase system with four conductors the power absorbed is obtained by means of three wattmeters, the current coils of which are connected in the three

supply mains, and the pressure coils of which are placed between these mains and the common return or neutral wire. The proof is given on page 129. The energy is measured by three single-phase induction meters connected in the same manner, as shown in Fig. 184. The sum of the three readings will give the total energy consumed. It is, however, not necessary to use three instruments, as a single polyphase meter can be used when specially designed for a three-phase four-wire system. The principles involved in the construction of such a meter will be found in the latter part of Chapter VII., and it will be seen that they differ from those on which the ordinary polyphase meter is based. In other words, a meter suitable for a three-phase three-wire network (or two-phase with three and four wires) will, in general, not measure the energy in a three-phase system with four conductors.

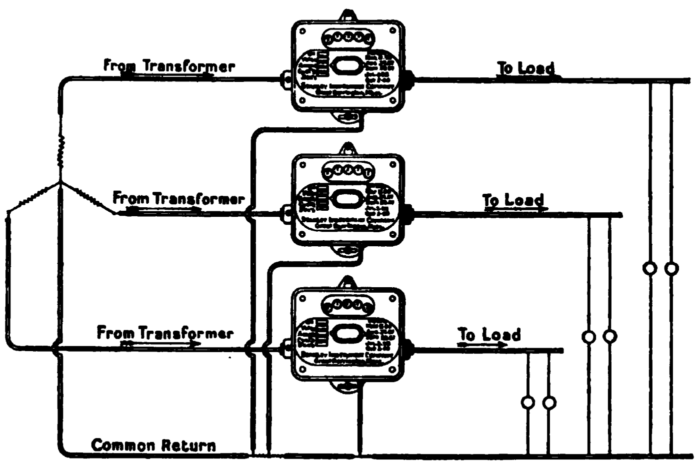

FIG. 184.

Behaviour of Three-phase Three-wire Induction Meters on Inductive Loads.—Before proceeding to the descriptions of the polyphase meters (for unbalanced loads only) included in this chapter, a few general remarks may prove of interest in connection with the behaviour of a three-phase three-wire meter when the load is inductive and equally distributed between the phases. In this case, as already explained, the mean power is given by the equation

$$P = V_1 C_1 \cos(\phi - 30°) + V_1 C_1 \cos(\phi + 30°).$$

The driving torque D_1 of the one motor element of the polyphase meter is proportional to $V_1 C_1 \cos(\phi - 30°)$, and the driving torque D_2 of the second motor element is proportional to $V_1 C_1 \cos(\phi + 30°)$, the total torque being proportional to their algebraic sum.

When $\phi = 0$, then $D_1 \propto V_1 C_1 . \frac{\sqrt{3}}{2}$, $D_2 \propto V_1 C_1 . \frac{\sqrt{3}}{2}$, and the speed of the meter is proportional to $\sqrt{3} . V_1 C_1$, *i.e.* the true power.

When $\phi = 30°$, then $D_1 \propto V_1 C_1$, $D_2 \propto V_1 C_1 \frac{1}{2}$, and the speed of the meter is proportional to $\frac{3}{2} V_1 C_1$, *i.e.* $\sqrt{3} . V_1 C_1 \cos 30°$, which is the true power when the angle of lag is 30°.

When $\phi = 60°$, then $D_1 \propto V_1 C_1 \frac{\sqrt{3}}{2}$, $D_2 = 0$, and the speed of the meter is proportional to $V_1.C_1.\frac{\sqrt{3}}{2} = \sqrt{3}.V_1 C_1 \cos 60°$.

When $\phi = 90°$, then $D_1 \propto \frac{V_1 C_1}{2}$, $D_2 \propto -\frac{V_1 C_1}{2}$, and the meter speed is proportional to $\left(\frac{V_1 C_1}{2} - \frac{V_1 C_1}{2}\right) = 0$, *i.e.* the meter stops, the power being zero, or $\sqrt{3}.V_1 C_1 \cos 90°$, as in this case the current and pressure are in quadrature.

When $\phi = -90°$, then $D_1 \propto -\frac{V_1 C_1}{2}$, $D_2 \propto \frac{V_1 C_1}{2}$, and the same result is obtained as when $\phi = +90°$.

When $\phi = -60°$, then $D_1 = 0$, and $D_2 \propto V_1.C_1 \frac{\sqrt{3}}{2}$, and the meter speed is proportional to $\sqrt{3}.V_1 C_1 \cos(-60°)$ which is the same as $\sqrt{3}.V_1 C_1 \cos 60°$.

Finally, when $\phi = -30°$, the same ultimate result is obtained as when $\phi = +30°$, but D_1 is now proportional to $\frac{1}{2} V_1 C_1$ and D_2 to $V_1 C_1$.

Condition for Use of one Single-phase Induction Meter.—It has already been shown that when the three-phase three-wire system is perfectly balanced, and no displacement exists between the current and the pressure, one single-phase induction meter suffices for the measurement of the energy, but in no other case.

It must be remembered that unless the integrating mechanism is specially geared, its indications must be multiplied by the factor 2.

If, however, the current and pressure be not in phase, although the three branches may be in perfect balance, then it is incorrect to use a single-phase meter in this manner. This is easily shown as follows. The meter reads either

$2\int_{T_1}^{T_2} V_1 C_1 \cos(\phi - 30°)dt$, or $2\int_{T_1}^{T_2} V_1 C_1 \cos(\phi + 30°)dt$. Now the true energy is $\int_{T_1}^{T_2} \sqrt{3}.V_1 C_1 \cos \phi dt$. Hence, when the meter reads $2\int_{T_1}^{T_2} V_1 C_1 \cos(\phi - 30°)dt$, its indications will be too high, since

$$2\int_{T_1}^{T_2} V_1 C_1 \cos(\phi - 30°)dt = \int_{T_1}^{T_2} V_1 C_1 \sqrt{3}.\cos \phi dt + \int_{T_1}^{T_2} V_1 C_1 \sin \phi dt,$$

and when it reads $2\int_{T_1}^{T_2} V_1 C_1 \cos(\phi + 30°)dt$, the meter will be under-registering.

If $\phi = 30°$, then in the former case the meter reads $33\frac{1}{3}$ per cent. high, and in the latter $33\frac{1}{3}$ per cent. low. When $\phi = 60°$, the meter reads either 100 per cent. high, or it stops, and when $\phi = 90°$, in which case the power absorbed is zero, the meter indicates as though its speed were approximately

proportional to ·58 times the true three-phase power when the load contains neither self-induction nor capacity, or it revolves at this rate in the reverse direction.

Effect of Wrongly Connecting a Three-phase Three-wire Meter.—It has already been shown that a three-phase three-wire meter is, in general, connected to the circuit on the two-wattmeter method of connection. The instrument is usually provided with six terminals, which are divided into two sets, one for each of the two single-phase motor elements comprising the meter. Each set has generally one shunt terminal and two main current terminals, of which the one is for the supply and the other for the load. When the meter has been properly installed its disc will revolve in the correct direction, which is indicated by an arrow on the meter cover, and it will function correctly. The inference must not, however, be drawn that the correct direction of rotation of the disc is in itself a sufficient guarantee that the indications of the meter will be correct. It is, in fact, quite possible to so connect the meter that the disc will be revolving as shown by the arrow, but it will be registering quite wrongly. It must be remembered that

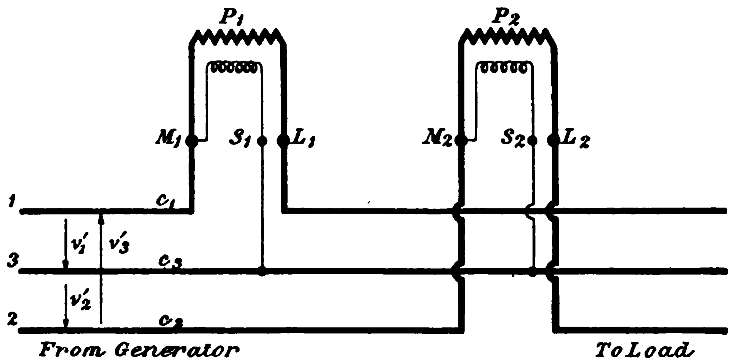

FIG. 185.

a definite relationship exists between the different connections, and that the meter will only function in a proper manner when this relationship is observed. In actual practice it often happens that the person installing a three-phase three-wire meter knows nothing definite as to the phase conditions of the three supply mains, and has no information of the power factor of the load. It is then quite possible for him to easily make an error in the connections, especially the shunt connections; and although he may, on closing the circuit, obtain a correct direction of revolution of the disc, the meter in all probability will be registering either too high or too low.

The two-wattmeter method of connection may be carried out in three different ways, as illustrated diagrammatically in Figs. 185 to 187. The result obtained is, however, exactly the same in each case. In all these diagrams P_1 and P_2 represent the two motor elements of the meter, and for the sake of clearness P_1 and P_2 may be regarded as two distinct single-phase induction meters. The letters v' and c denote respectively the instantaneous values of the pressures between the supply mains and the currents in those mains. M_1 is the supply terminal, L_1 is the corresponding terminal to the load, and S_1 is the shunt terminal of the meter P_1, the letters M_2, etc. having the same significations for the meter P_2.

Referring to Fig. 185, the series circuit of the meter P_1 is placed in the supply main No. 1, whereas that of the meter P_2 is placed in main No. 2, and the shunt connections have in this case to be brought from the two shunt terminals S_1 and S_2 to the third supply main No. 3. The instantaneous value of the power is

$$p = v'_1 . c_1 - v'_2 . c_2 .$$

When the system is perfectly balanced, the mean power has been shown to be given by

$$P = V_1 . C_1 . \cos(\phi - 30°) + V_1 . C_1 . \cos(\phi + 30°),$$

V_1 and C_1 being the R.M.S. values respectively of the P.D. between any two of the supply mains and the current in any one of these mains, $\cos \phi$ denoting the power factor of the load. The one meter P_1 revolves at a rate proportional to $V_1 C_1 \cos(\phi - 30°)$, and the second meter P_2 rotates at a speed proportional to $V_1 . C_1 . \cos(\phi + 30°)$, their algebraic sum being proportional to the true power, *i.e.* $\sqrt{3} . V_1 . C_1 . \cos \phi$.

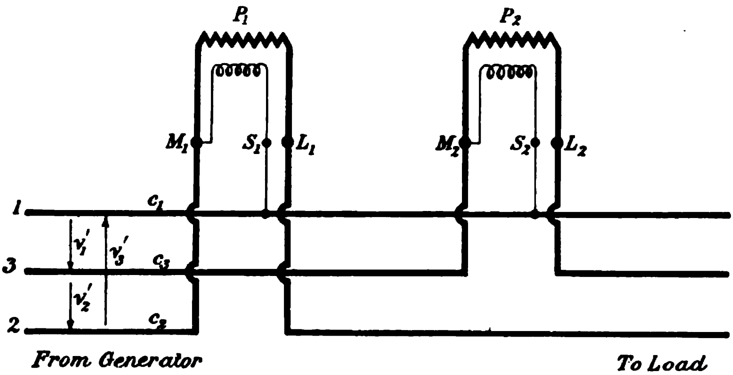

FIG. 186.

Instead, however, of placing the series circuits of the two meters in the mains 1 and 2, they may be placed in the mains 2 and 3, as shown in the diagram Fig. 186, when the shunt terminals have to be connected to main 1.

The mean value of the power is now given by

$$p = v'_3 . c_2 - v'_1 . c_3 ,$$

and the two meters indicate in exactly the same manner as in the previous case. P_1 will be proportional, as before, to $V_1 . C_1 . \cos(\phi - 30°)$ and P_2 to $V_1 . C_1 . \cos(\phi + 30°)$. It may be pointed out here that the two meters would function correctly if P_1, instead of being connected as a single-phase meter to mains 1 and 2, were connected as P_2 is, and the corresponding change be also made as regards P_2. The sum of their readings would indicate the true three-phase energy, but in all probability they both would rotate in the opposite direction, as P_1 would now be proportional to $V_1 . C_1 . \cos(\phi + 30°)$, and P_2 would be proportional to $V_1 . C_1 . \cos(\phi - 30°)$.

The third method of connection is shown in diagram Fig. 187, and the instantaneous value of the power is

$$p = v'_2 . c_3 - v'_3 . c_1 .$$

P_1 is again proportional to $V_1 . C_1 . \cos(\phi - 30°)$ and P_2 to $V_1 . C_1 . \cos(\phi + 30°)$.

It will be observed from the above that the two series circuits of the polyphase meter may be placed in any two of the three supply mains, but that the free ends of the two pressure circuits (*i.e.* the shunt terminals) must be connected to that main which does not pass through the meter.

It seems advisable to first connect the shunt terminals of the meter to any one of the three supply mains, then to bring the remaining supply mains into

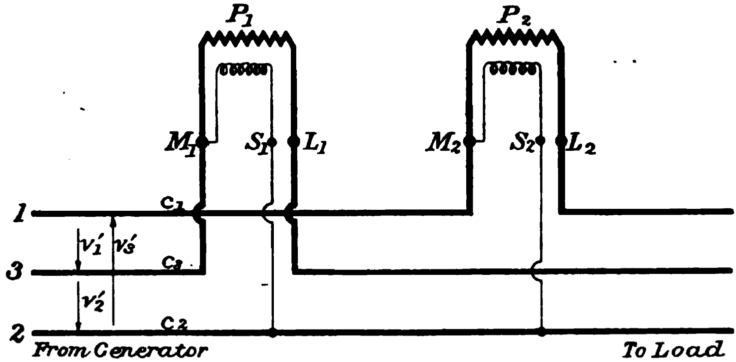

FIG. 187.

the two supply terminals (in the diagrams marked M_1 and M_2), and complete the connections on the load side of the meter. If the meter revolve in the wrong direction on closing the circuit, it is only necessary to disconnect the two supply mains entering the meter (at M_1 and M_2) and to interchange them, when the meter will rotate as indicated by the arrow on its cover, and will function correctly. The terminals of the meter should be lettered in

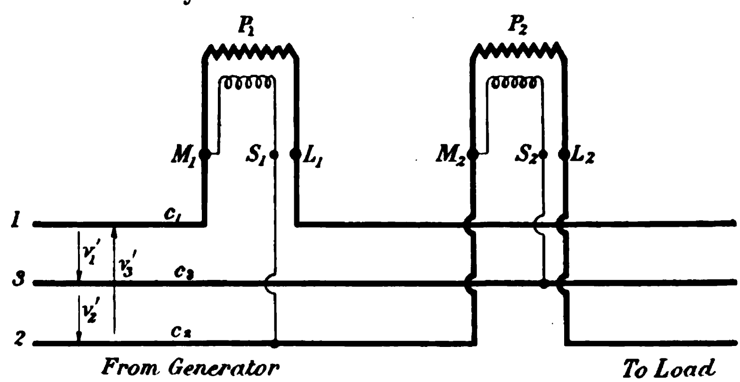

FIG. 188.

some distinctive manner, especially those for the shunt connections, and, further, the three supply mains should always be furnished with some distinguishing mark.

In Fig. 188 is shown diagrammatically a three-phase three-wire meter *improperly* connected to the system. The series circuits of P_1 and P_2 are placed in the mains 1 and 2, as in Fig. 185, but one of the pressure circuits is wrongly connected. S_1 should be joined to main No. 3; S_2 is properly connected.

The meter will, generally, read incorrectly. Assuming a balanced system, some interesting results may be established. If the currents and pressures be exactly in phase, *i.e.* cos $\phi = 1$, the meter will read correctly. A very slight deviation, however, from unity power factor will cause a very large error, and this should be borne in mind, as in actual practice exact coincidence in phase between the current and the pressure is never realised. Even when the load consists entirely of incandescent lamps, the power factor is not exactly unity, and the above result only holds when it is absolutely so.

If the power factor be ·866, *i.e.* $\phi = 30°$, the meter in this case will read $33\frac{1}{3}$ per cent. low, whereas with a power factor of ·5, *i.e.* $\phi = 60°$, the meter will stop, the true power being, however, $\sqrt{3}.V_1.C_1.$ cos $60°$, *i.e.* $\frac{1}{2}\sqrt{3}.V_1.C_1$. For power factors less than ·5 the meter reverses, and when the current and pressure are in quadrature, *i.e.* the true power is $\sqrt{3}.V_1.C_1.$ cos $90° = 0$, it continues rotating in the reverse direction and at a speed approximately proportional to ·58 times the three-phase power when the power factor is unity.

On the other hand, if the meter be *wrongly* connected, as indicated in Fig.

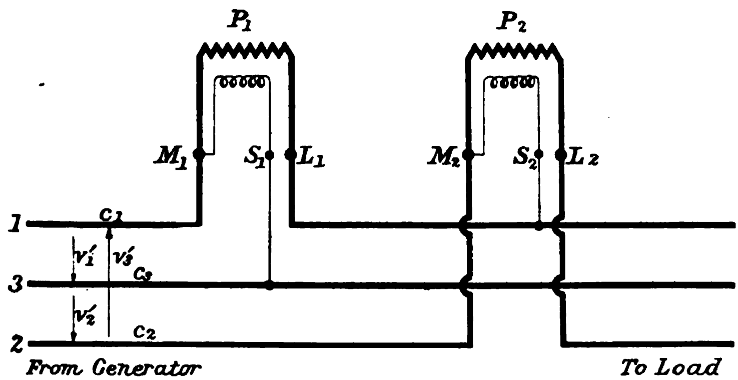

FIG. 189.

189, it will generally read high, except for a unity power factor, when it will register correctly as in the former case. When the power factor is ·866 ($\phi = 30°$) it will be $33\frac{1}{3}$ per cent. high, and when the power factor is ·5 it will read 100 per cent. high. As the power factor decreases from this value the error will also grow less, and when the power factor has fallen to zero, *i.e.* $\phi = 90°$, the meter, still rotating in the same direction, will have a speed approximately proportional to ·58 times the power when the power factor is unity.

Other incorrect methods of connection will readily suggest themselves to the reader, who will be easily able to determine the degree of inaccuracy (+ or −) for different power factors from the equations and principles given in Chapter VII.

It may be as well to emphasise the fact that, when the system is unbalanced, the polyphase meter *wrongly* connected will always give incorrect results.

With some polyphase meters special connections have to be employed, more particularly with three-phase four-wire meters. In such cases it is essential to know exactly the order in which the supply mains are to be taken, and in a four-wire system, which is the fourth or neutral conductor. In

practice, the correct sequence of the three supply mains is tested by the employment of a three-phase rotary field direction indicator, such as that manufactured by the Siemens-Schuckert Werke, Berlin. The fourth or neutral conductor of a three-phase four-wire system is easily determined by means of a voltmeter.

In installing meters for single-phase or polyphase circuits with transformers (current, pressure, or both), care should be taken to ascertain whether the transformer will introduce any modifications in the connections to the meter. With single-phase meters this is not of very great importance, as the correct direction of rotation of the meter disc means the proper working of the meter. Consequently if, after connecting with the transformer or transformers, the

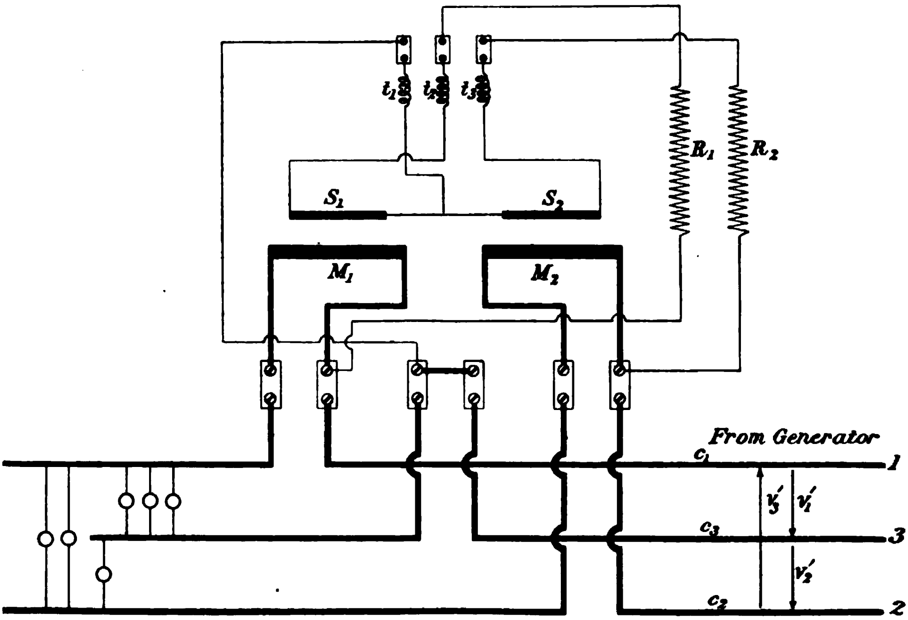

FIG. 190.

direction be wrong, it is easily rectified by altering the meter connections. This, in the case of polyphase meters, only holds when the primaries of the transformers have been properly connected to the three supply mains, and the two sides of the meter have been correctly joined to the secondaries of the right transformers.

The reason for the modification introduced by the transformer is that in some designs the currents in the primary and secondary circuits of the transformer are at every moment reversed relatively to one another, and this may affect the connections to the meter.

Aron Polyphase Meters.—The earliest Aron clock meters for three-phase three-wire circuits were based on the equation

$$3p = v'_1(c_1 - c_3) + v'_2(c_3 - c_2) + v'_3(c_2 - c_1),$$

the letters denoting the instantaneous values of the currents in the three supply mains and the pressures between them. Six main current and three

pressure coils were consequently required, resulting in a very complicated instrument. This method was, however, very quickly abandoned and a new one developed, which forms the basis of all polyphase three-wire meters on the two-wattmeter method, the equation for the instantaneous power becoming

$$p = c_1.v'_1 - c_2.v'_2,$$

the proof of which was given on page 120.

In Fig. 190 is given a diagrammatic sketch of the Aron three-phase three-wire meter. M_1 and M_2 denote the stationary main current coils, and S_1 and S_2 are the pressure coils carried on the two pendulums, S_1 and M_1 operating together and also S_2 and M_2. R_1 and R_2 are suitable resistances in the two pressure circuits, and t_1, t_2, t_3 represent three flexible spiral connections by means of which the pressure currents are conducted to and from the swinging volt coils.

Dr Aron was not only the first to construct three-phase three-wire meters, indicating the general method to be adopted, but also established the formulæ for the construction of three-phase meters for systems with four conductors,

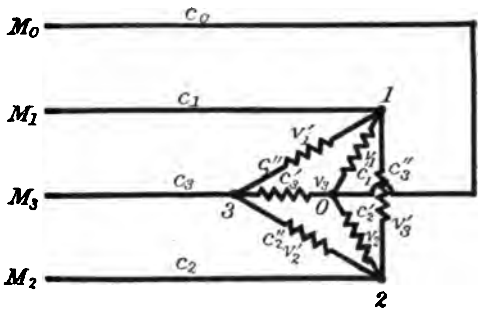

FIG. 191.

and designed clock and motor meters for this purpose. The instantaneous value of the power for a three-phase four-wire system (Fig. 191), as shown on page 128, is

$$p = v_1c_1 + v_2c_2 + v_3c_3,$$

This equation reduces to

$$p = v_1(c_1 - c_3) + v_2(c_2 - c_3),$$

which may be written

$$p = v_1c_1 + v_2c_2 - c_3(v_1 + v_2) \quad . \quad . \quad . \quad . \quad . \quad \text{(i)}.$$

In Fig. 192 is shown diagrammatically the arrangement of the main current and pressure coils of an Aron clock meter based on equation (i). S_1 and S_2 are the shunt coils on the two pendulums, arranged in such a manner that the current c_1 in the coil A acts on the pendulum carrying the shunt coil S_1, energised by a current proportional to v_1. The current c_2 in the coil B acts on the volt coil S_2 of the second pendulum connected across M_2 and M_0. The central coil C carries the current c_3 in the main M_3 and acts on both the pendulum coils. As it is necessary to retard one pendulum and accelerate the other, the two shunt coils are so connected that they always produce

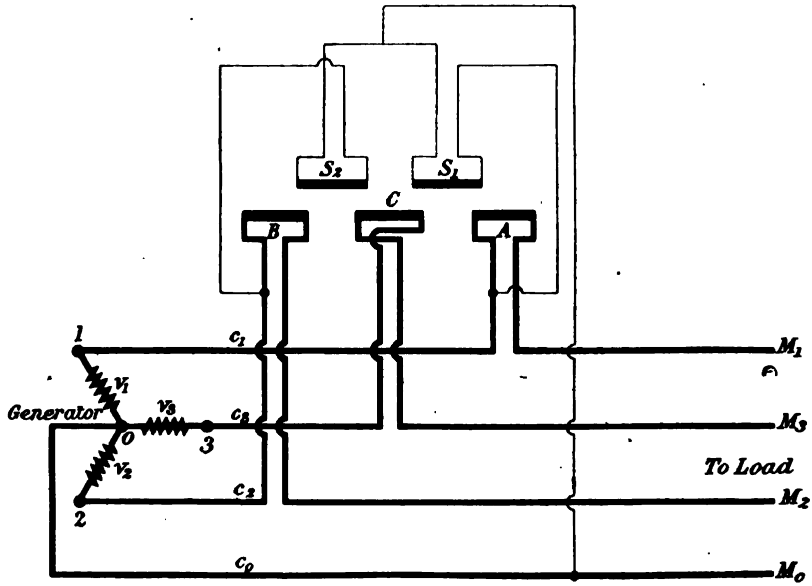

FIG. 192.

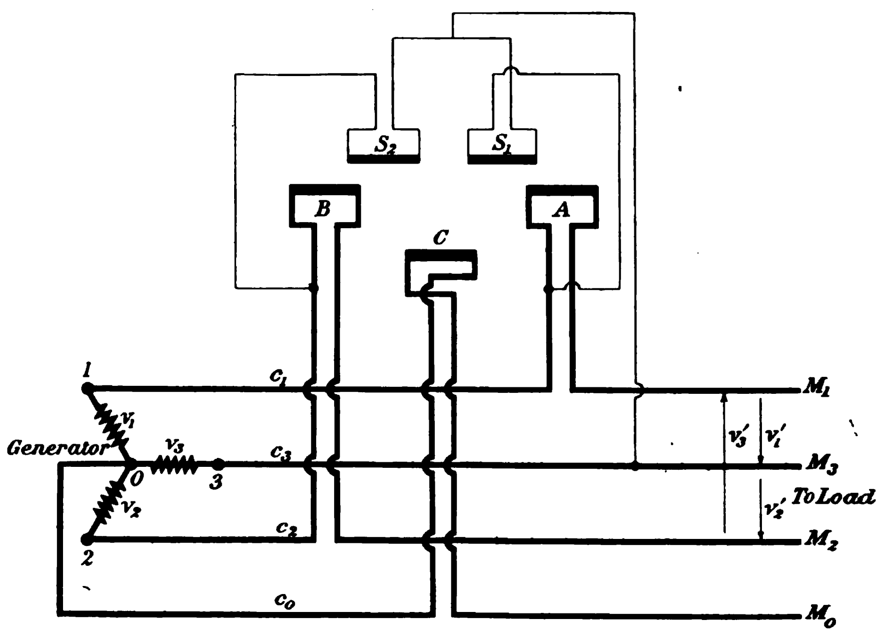

FIG. 193.

opposite polarities relatively to one another; while the currents in the coils A and B circulate in the same direction, that in coil C flows in the opposite direction. The above equation (i) requires that the current coils should be so arranged that they affect the pendulums equally. This is, however,

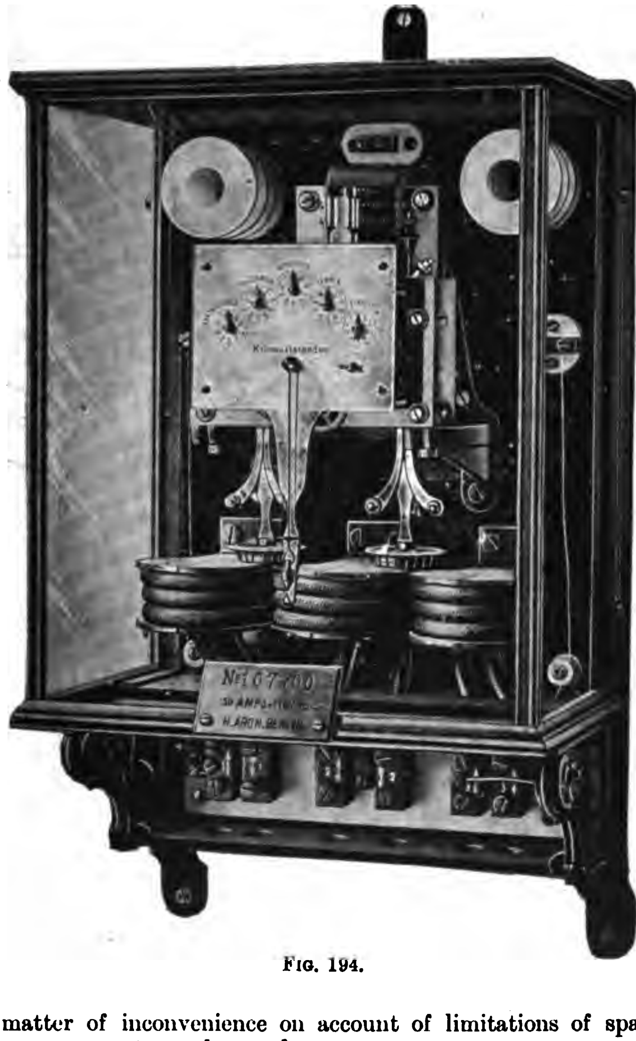

FIG. 194.

often a matter of inconvenience on account of limitations of space, and a different arrangement can be used.

Equation (i), as shown on page 130, can be transformed into

$$p = v'_1\left(c_1 + \frac{c_0}{3}\right) - v'_2\left(c_2 + \frac{c_0}{3}\right) \quad . \quad . \quad . \quad . \quad \text{(ii)}.$$

i.e.

$$p = v'_1 c_1 - v'_2 c_2 - \frac{c_0}{3}\left(v'_2 - v'_1\right) \quad . \quad . \quad . \quad . \quad \text{(iii)}.$$

Equation (iii) shows that the middle coil can be placed at a greater distance from the two pendulums than the other two; it also carries the current in the

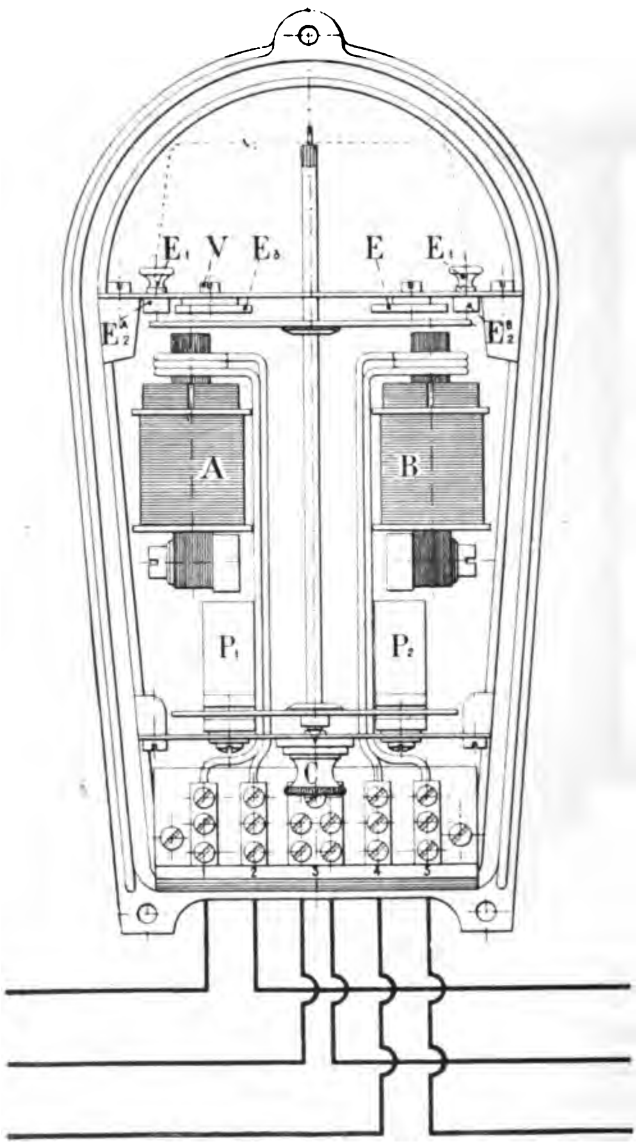

FIG. 195.

fourth conductor M_0, and must be adjusted so that its effect is only equal to one-third of the current in the neutral conductor M_0. The connections of the coils are also quite different from the former case, and are shown in Fig. 193;

it will also be seen that the pressures used are now not those between the mains and the fourth conductor.

A complete three-phase four-wire Aron meter is illustrated in Fig. 194, and is based on equation (i).

The Bat Polyphase Meters.—The Bat two-phase, or three-phase, three-wire meter is illustrated in Fig. 195, which shows the arrangement of the various parts. It consists of two single-phase motor-meter elements, each of which is similar to that used in the single-phase type, and both these driving systems act upon the same disc. A separate brake disc mounted on the lower part of the axle is used, and it revolves between the poles of two permanent magnets.

The method of connection is the ordinary two-wattmeter one, as will be seen from the illustration. The driving torque exerted on the armature disc by each motor element should be the same for the same load. The adjustment is made by lowering or raising the iron plate E_3, Fig. 195, by means of the screw V, until the torque exerted by the part A is equal to that produced by B, each side being tested on the same load as a single-phase meter. When the disc E_3 is lowered the torque of A will be increased.

It is important to bear in mind that, whichever motor part (A or B) is being tested, the shunt coils of the two motor systems must always be energised, otherwise errors will be introduced. The reason is that the one shunt system acts as a brake to the other; and unless both the shunts be energised in testing the meter, it will read low when connected to a three-phase installation. This applies to any three-phase meter of this type.

FIG. 196.

The Bat Meter Company also supply a special three-phase four-wire meter. The general construction of the meter will be followed from the front view of the instrument given in Fig. 196. Two pairs of main current and two pairs of shunt coils operate on the top armature disc, producing two driving systems very similar to those used in the three-phase three-wire meter, the difference being as regards the connections of the coils and their effect on the disc.

The principle of the meter is based on the equation

$$p = v_1(c_1 - c_2) + v_3(c_3 - c_2),$$

the letters denoting instantaneous values, and the proof of the equation is given on page 130. The method of connection is shown diagrammatically in Fig. 197.

M_1 and M_2 are the two main current, and S_1 the shunt, coils of the one motor system which act together on the disc, and M_3, M_4, and S_2 are the

corresponding coils of the second motor element. M_1 is placed in main No. 1, M_2 and M_3 are connected together in series and placed in main No. 2, and M_4 is in main 3, the shunt coils S_1 and S_2 being connected between the fourth or neutral wire and the mains 1 and 3 respectively. The meter will give the total three-phase energy, however unbalanced the circuits may be.

The Electrical Company's Three-phase Meter.—The three-phase meter for three-wire circuits of the Electrical Company, Ltd., London, possesses the characteristic feature of having only one pressure circuit in contrast to the two pressure circuits of most polyphase meters with the two-watt-meter method of connection. In this manner the shunt loss is kept small, the construction of the meter is simplified, and the troubles due to rupture of the fine wire of the pressure circuit are minimised. The result is obtained by assuming that the three tensions of the system are always equal to one another. It will be followed by reference to Fig. 198, which represents a diagram of connections of the meter, and to the vector diagram in Fig. 199. M_1 and M_2 are the two main current coils of the meter, and S_1 and S_2 are the shunt coils producing respectively with M_1 and M_2 the rotary fields which drive the disc; I is the impedance coil. With the connections as shown the pressure used is v'_1. The pressure current c'_2 is displaced 30° with reference to the phase of v_1 and operates with the current in M_2. It will be seen from Fig. 199 that the flux due to c'_2 in S_2 is at right angles to v_2, *i.e.* to the flux produced by the

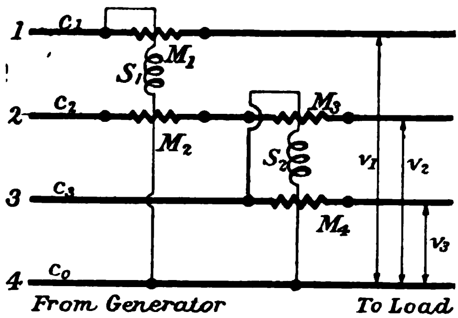

Fig. 197.

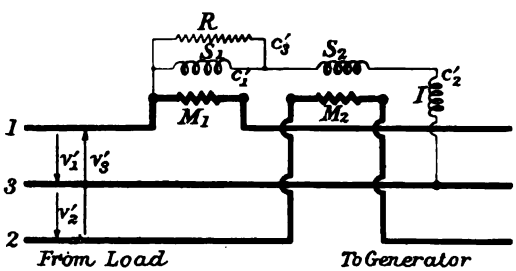

Fig. 198.

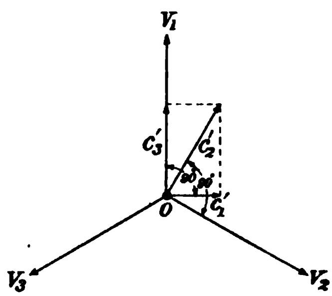

Fig. 199.

current in the main coil M_2 when the load is non-inductive. The pressure current c'_2 is split into two portions by means of the non-inductive resistance R in parallel with the coil S_1, so that the pressure current c'_1 in this coil operating with M_1 is at right angles to v_1, and the shunt and main current fluxes are again displaced by a quarter period when the load is an inductionless one, the other component of the shunt current c'_3 in the non-inductive resistance being in phase with v_1. The total torque on the disc is thus proportional to the true power absorbed. The meter, with the cover removed, is shown in Fig.

200. The construction of each motor element is very similar to that employed in the single-phase meter, type K.J. (see page 135). One choking coil is used, and a secondary winding is wound on the central limb of the right-hand magnet. The conductivity of this winding is adjusted by means of the sliding contact, clearly shown in the illustration, in obtaining the requisite phase relationships, together with the non-inductive resistance on the left of the meter spindle. The same disc is operated upon by both motor elements and acts as the brake disc, revolving between the poles of a permanent magnet.

Three-phase A.C.T. Meter.—This meter of the Compagnie pour la

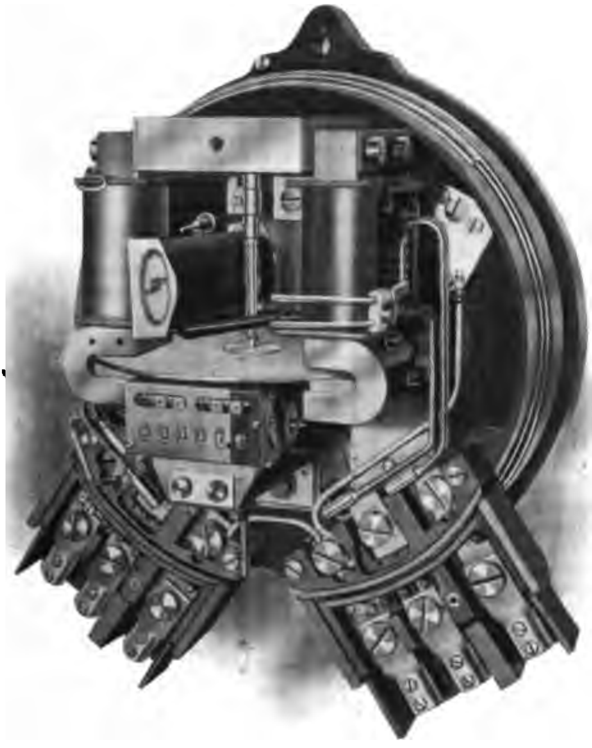

Fig. 200.

Fabrication des Compteurs, Paris, consists of a combination of two of their A.C.T. single-phase meters driving a single disc, the work done being absorbed by the brake magnet. Each meter system consists of a pressure coil and two main current coils, the latter being in parallel with one another, and wound in opposite senses. The quarter-phase displacement between the shunt and series fluxes is obtained with each system, when the load is a non-inductive one, by means of the adjustable resistance in series with one of the main current windings, in exactly the same manner as for the A.C.T. meter described in Chapter VIII. The other adjustments are also similar.

The Deutsch-Russische Three-phase Meter.—The three-phase meter of

the Deutsch-Russische Electricitätszähler-Gesellschaft, Germany, consists of two of their single-phase induction meters, type W.J., described on page 145. The two meters are mounted together on one common base, as will be seen from the illustration given in Fig. 201, and the sum of the readings of the two counters gives the total three-phase energy consumption. With this arrangement the state of balance of the phases of the system can be readily determined, and the two meter readings will be exactly the same when the three-phase system is perfectly balanced and the power factor is unity.

Fort Wayne Polyphase Meter.—The polyphase induction meter of the Fort Wayne Electric Works, Fort Wayne, Indiana, U.S.A., consists of two of their type K induction motor-meter elements operating upon one aluminium cylinder, the speed of which is controlled in the usual manner by two adjustably mounted vertical permanent magnets. The general arrangement is very clearly shown in the view given in Fig. 202 of the switchboard meter, and the connections are made on the ordinary two-wattmeter method.

FIG. 201.

Two sets of series coils, one in each side of a two-phase four-wire or two- or three-phase three-wire circuit, are mounted on arms screwed to the lower brackets, and together with the shunt coils produce the total driving torque on the cylinder. The impedance coils used in each pressure circuit are situated at the bottom of the instrument. The adjustments for each motor system are made in exactly the same manner as in the single-phase meter, type K, described on page 162.

Siemens-Schuckert Polyphase Meters.—The Siemens-Schuckert Werke manufacture two types of three-phase meters for unequally loaded three-phase three-wire systems. Their U.D. type, Fig. 203, is simply a combination of two of their single-phase meters, a description of which has been given on page 141. The revolving element is composed of an axle, on which are mounted two aluminium drums, an aluminium brake disc, and a worm to convey the rotations of the spindle to a counting train. The work done by the two induction motors is absorbed by the brake disc, rotating between the poles of a permanent magnet. The drum of each induction motor is driven by the rotary magnetic field, produced by the two main current coils, and the two pressure coils, which are wound on the four poles of the motor frame. The 90° phase displacement, between the shunt and series fluxes of each meter system, when the load is non-inductive, is produced in exactly the same

manner as in the corresponding single-phase type. Denoting the three-phase mains in order by the numbers 1, 3, and 2, the main current coils of the one motor are traversed in series by the current in main 1, and those of the second motor by the current in main 2. The pressure coils of the first motor are then placed in series across the three-phase wires 1 and 3, and the remaining pressure coils are connected in series between the branches 2 and 3. The same method of trembling support of the moving system is used as in the case of the single-phase meter.

Fig. 204 is a general view of the Siemens-Schuckert three-phase meter, type F.U., and in Figs. 206–208 are given the details of its constituent parts.

Two aluminium discs mounted on the same axle comprise the armature of

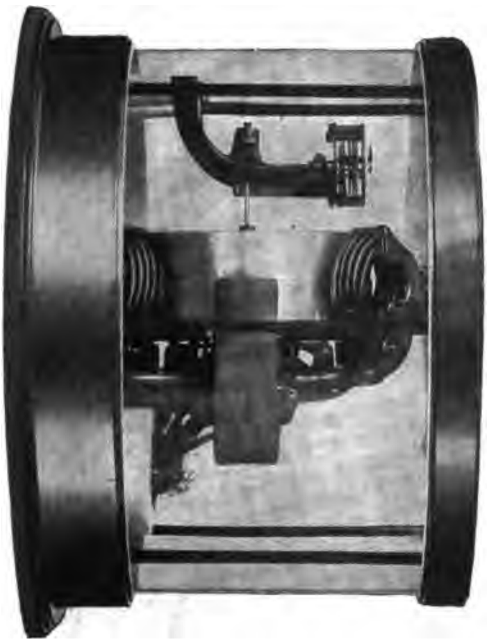

FIG. 202.

FIG. 203.

the meter. Each disc is acted upon by two main current coils, and either one or two shunt coils, according to the pressure, each shunt coil being wound on one of the vertical limbs of a laminated iron magnet, in the air-gap of which the disc rotates. The main current coils of the first disc are connected in series and are traversed by the current in the main 1 of the three-phase system. The one main current coil of the second disc carries the current in main 3, and the other has flowing in it the current in main 2. The two (or four shunt) coils are coupled together in star with an impedance coil, and their free ends are connected to the three sides of the three-phase network. The method of connection is illustrated diagrammatically in Fig. 205. The two main current coils, connected in series, of the upper disc, are represented by $M_1 + M_2$, and they operate with the shunt coil or coils S_1. M_3 and M_4 denote the two remaining current coils, which, in conjunction with the shunt

coil or coils S_2, drive the lower disc. I is the impedance coil, in star with S_1 and S_2.

The equation upon which the meter is based, viz.

$$2p = c_1(v'_1 - v'_3) + v'_2(c_3 - c_2),$$

has been explained in Chapter VII., on page 128. Each of the two discs,

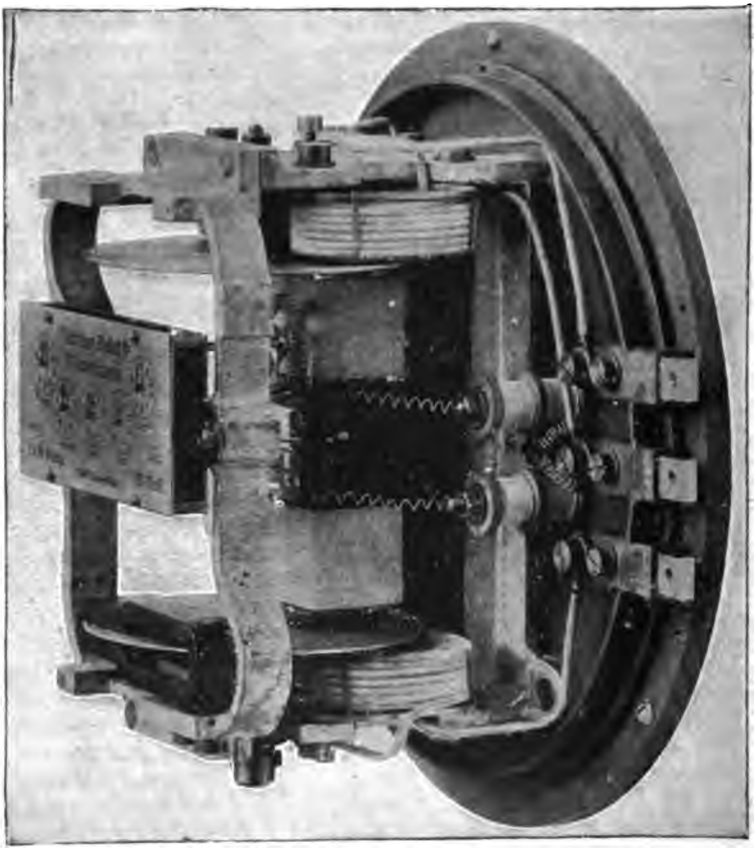

FIG. 204.

further, rotates between the poles of a permanent magnet, which induces the retarding eddy currents.

Three aluminium castings are used to support the different elements of the meter. These consist of the circular base (Fig. 204), on which the whole meter is mounted, the E-shaped bracket (Fig. 206), which serves to carry the revolving element, and the shunt and series systems, and finally the front frame, to which are attached the integrating train and brake magnets, as shown in Fig. 204. The revolving element consists of two aluminium discs, which are ribbed to increase their rigidity, and are attached to the common spindle by means of brass hubs, the one near the top and the other at the

lower end. A small fan to balance the moving system is carried on the spindle in addition to the two discs and the brass driving worm. The revolving element, with the lower disc removed, is clearly shown in Fig. 208.

The electrical details of the series and shunt systems are given in Fig. 207. Two views of a main current coil are shown at *h*, very clearly illustrating the method employed in fixing the same, and the construction of the laminated rectangular shunt magnet S_1 will be understood by reference to its parts *a*, *b*, and *c*. A shunt coil is also shown below the magnet at D. The series coils are oblong in shape and are mounted one on each side of the shunt magnet (Fig. 206). The bolts securing them to the E-shaped bracket pass through slots in the latter, so that the position of the coils can be altered for adjusting the instrument. The impedance coil is constructed in the same manner as the shunt magnets, and is fixed to the base of the meter.

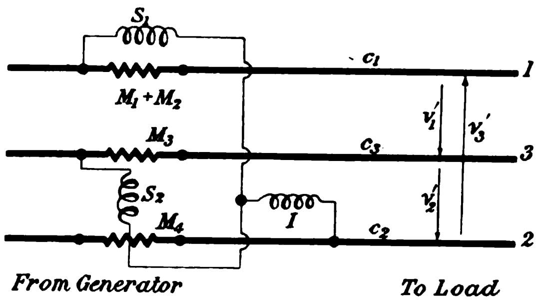

Fig. 205.

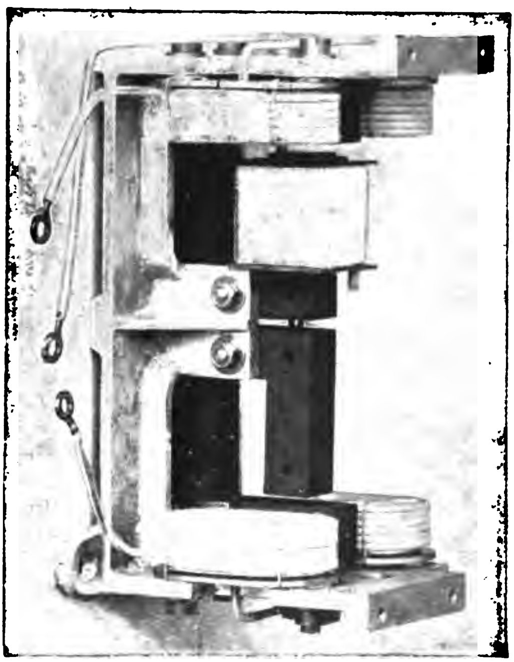

Fig. 206.

A very easy and sensitive adjustment for compensating for friction on light loads is obtained by the use of a small iron bolt, shown on the right in Fig. 208, above the upper aluminium disc. This bolt, or starting screw, is inserted in either the right- or left-hand hole in the top ledge of the E-shaped bracket. According to its position, in which it is secured by a lock-nut, it produces a rotation either to the left or to the right. The supplemental torque exerted in this manner results from the attraction between the iron bolt and the eddies induced in the disc by the shunt magnet, and its magnitude depends on the height of the bolt above the disc. The difference in phase between the shunt and series fluxes of each system is adjusted by means of non-inductive resistances connected to the shunt coils, and the speed of the meter at the high

loads can be varied by moving the damping magnets, which are adjustably mounted relatively to the discs for this purpose. The driving torque can, if required, be also changed, as each main current coil admits of lateral displacement, as already explained.

Thomson Polyphase Induction Meter.—The general arrangement of the Thomson polyphase watt-hour meter of the British Thomson-Houston Company, Rugby, and the General Electric Company, Schenectady, U.S.A., suitable for balanced and unbalanced two-phase or three-phase three-wire circuits, will be understood from the illustration of the Switchboard type in Fig. 209. The revolving disc is driven by two electrical systems, each of which consists of a potential coil carried on a laminated iron magnet, and two series coils without iron, arranged on either side of the shunt magnet and below the

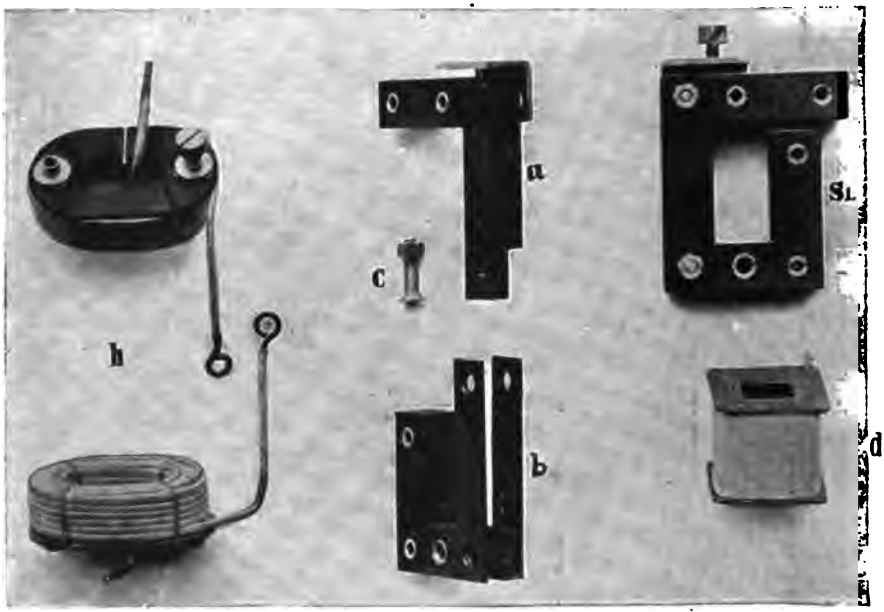

FIG. 207.

disc, the potential coil being above the latter. Each shunt or potential coil is in series with an impedance coil. The retarding torque is obtained from two magnets, each magnet belonging to its particular electrical system. The light load adjustment consists in slightly displacing the potential coils above the disc, and is made with the current flowing in one set of main coils only, that is, treating the instrument as a single-phase meter, running on about $\frac{1}{20}$ non-inductive load; both pressure circuits must, however, be energised. If the meter run slow the potential core must be moved in a direction opposite to the direction of rotation of the disc by means of two screws in the top of the support. This operation should be repeated for the other motor system to effect a satisfactory adjustment.

A non-creeping device is used, and is simply a piece of iron wire attached to the hub of the disc. The wire stands parallel to the meter shaft and, if creeping should occur, is slightly inclined radially away from the shaft.

The Westinghouse Polyphase Meter, for both balanced and unbalanced loads, consists simply of two single-phase meters, that is, of two electro-magnetic systems acting upon two discs, mounted on a common shaft, each disc having its own magnet. The method of connection is on the same principle as that used in the ordinary two-wattmeter method of measuring power in

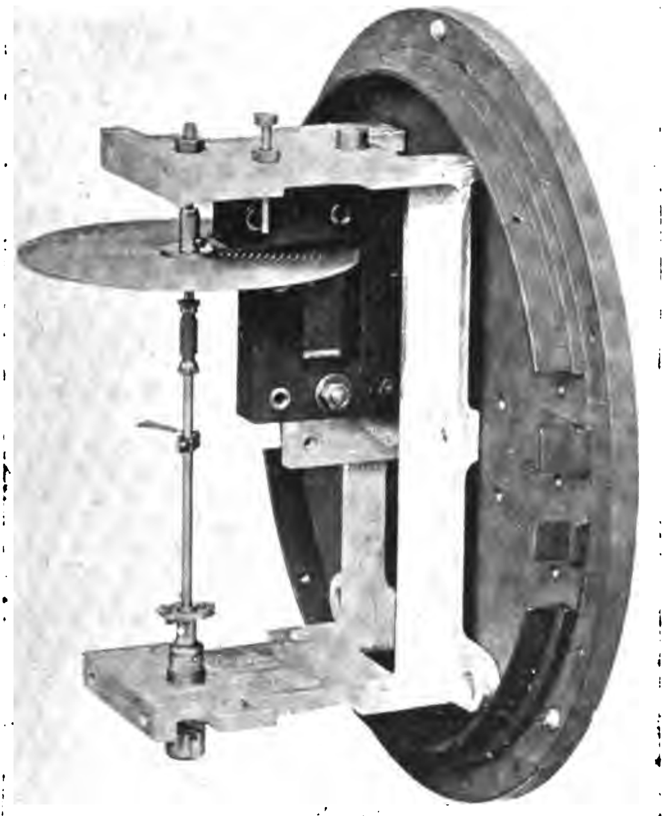

FIG. 208.

a polyphase circuit, the total torque exerted on the meter shaft being an algebraic sum of the torques on the two discs, as the total power would be the sum of the two wattmeters. The common spindle drives a single integrating train, which registers direct the total energy supplied to the polyphase system and at all power factors. The current capacity marked on the dial of the meter is the current in each wire of the polyphase system, and the voltage is that across one phase.

Fig. 210 is a diagrammatic sketch of a polyphase meter connected to a three-phase system for the case in which both current and pressure transformers are used. For a two-phase circuit the connections are similar, the top connections going to one phase and the bottom connections to the other

phase. The full load speed is the same as in the single-phase type, namely,

FIG. 209.

fifty revolutions per minute, and is the rate of rotation of the shaft when

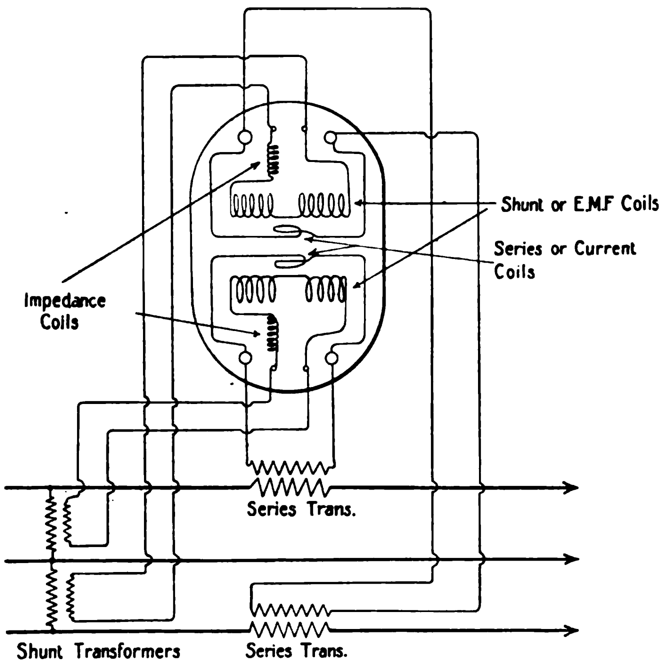

FIG. 210.

the watts on each circuit of the meter are equal to the rated watts, that is, to the product of the amperes and volts marked on the dial.

CHAPTER X.

Tariff Systems.

General—Flat Rate Systems with and without Discounts—The Manchester System—The Maximum Demand System—The Step-tariff System—The Halle Tariff System—The Two-rate System—The Prepayment System—The Hour Meter System—List of Papers on Systems of Charging.

General.—Great diversity of opinion exists in connection with electricity tarification, not only in this country but abroad. Numerous papers on systems of charging have appeared within recent years, and a list, by no means exhaustive, is appended in the interest of those desirous of further information on this important and complex subject, as it is only intended to give here in outline a few of the tariff systems in vogue as an introduction to the chapters on tariff and prepayment meters.

The cost of the generation and supply of electricity differs from that incident to the production and distribution of most commodities, because it cannot, in the present state of the electrical industry, be readily and economically stored, but has to be produced as it is required. The capacity of both the plant in the station and of the mains must be sufficient to meet the maximum possible demand which can be made at any time on the electricity undertaking by the various classes of consumers supplied, irrespective of the fact that the average load is considerably below this amount. Moreover, the supply station must always be in a state of readiness to deliver current whenever a supply is demanded, and whatever its magnitude. The price chargeable to a consumer is, therefore, not entirely governed by the quantity of units consumed, but depends to a large extent on the rate, the time, and the duration of the supply.

Dr John Hopkinson was the first to explain the principles underlying the cost of electricity supply, and to show that it may be divided into two classes—

(1) The cost incurred in preparing to supply (inclusive of the annual charges on capital outlay).

(2) The cost of maintaining the supply.

These two items of expenditure have been very appropriately termed "Preparation and Production Costs," respectively, by Mr Arthur Wright.*

The preparation costs, which are the heavier of the two, are independent of the actual output of the station at any time, whereas the production costs vary directly with the amount of electrical energy which is generated. In his presidential address to the Junior Engineering Society on 4th November

* "Some Principles underlying the Profitable Sale of Electricity," *Journal of the Institution of Electrical Engineers*, 1902, part 155, vol. xxxi.

1892, Dr Hopkinson formulated the maxim that there should be proportionality of charge to cost of supply, or, as he stated it, "the charge for a service rendered should bear some relation to the cost of rendering it."

The special tariff systems which have been introduced are all more or less based on the Hopkinson doctrine, but differ in the methods by which it is carried out in practice. The object aimed at is the ultimate use of electricity throughout the twenty-four hours of the day, whether for motive power, illuminating, heating, or other domestic purposes, and the equitable treatment of all consumers, irrespective of their demands and their use of the electric current, consistent with a profit comparable with that of other undertakings having the same risks.

Some consumers, from the nature and duration of their demand for current, are more profitable to the supply station than others, and it is generally endeavoured to give them every encouragement. On the other hand, no custom can very well be refused, in face of the keen competition with gas and hydraulic power companies, and that which exists amongst rival electricity undertakings. Electricity supply is as important and essential as a gas or water supply. With reference to those consumers who take current for lighting only, a large difference exists between the long-hour consumer and the short-hour consumer. The cost of supplying electrical energy to the former is less than that of supplying the short-hour consumer, on account of the preparation costs being so very much heavier in the case of the short-hour consumer, as he makes excessive demands on the station for relatively very short periods only, whereas the long-hour consumer's demand is at a much smaller rate, but is steadily maintained over long periods. The long-hour consumer is, therefore, a source of greater profit to the supply company than the short-hour user, although the latter's actual consumption may be very much greater. In addition to the above two classes of lighting consumers, there is the consumer who takes current during the day for power, heating, or cooking, or basement lighting. A considerably reduced price is made to such a consumer for a day supply of current. The total annual output of a station is largely increased by such day loads, and, consequently, the average cost per unit during the year is considerably diminished, so that a large reduction can be made. This large difference between the price for current for power and that for lighting is only justifiable on the ground that the demand for power is sufficiently large, and does not take place when current is used for illuminating purposes, *i.e.* is not coincident with the lighting peak hours. In winter, and when factories and other industrial establishments are working overtime, the demand for power and that for light will overlap, and no distinction should then be made between the two currents. When the current is used at this time, whether for motive power, lighting, or any other class of work whatever, the charge should be on the same basis as that obtaining for lighting only. In other words, no difference can be drawn between two currents of electricity with reference to the nature of the work they perform, but only as regards the time of day when they are used in relation to the cost of production.

Flat Rate Systems, with and without Discounts.—With a flat rate, or uniform tariff, one charge per unit is made. The advantage of this method of charging is, that it is readily understood by the public, and entails a minimum of clerical work in estimating the accounts. It gives, however, no encouragement to the general use of electricity during the day, nor does it offer any inducement to the long-hour consumer to continue his custom. Flat scales are in use in several small undertakings, but in the majority of

the large towns mixed systems are employed. In many instances discounts are given based on the quantity of electricity supplied, independent of the time and rate of demand. It is quite impossible, with advantage to the supply station, for consumers to be treated equitably on such a basis, as the cost of supply depends more on the rate of supply than on the total quantity delivered, although it is made up of both these factors. A user who, per quarter, six months, or year, takes the same total number of units as another, but at a considerably higher rate, makes a much heavier demand on the station and uses current for a shorter number of hours. He, therefore, costs more to supply, and his share towards defraying the expenses should be proportionately large.

The Manchester System.—This system of charging was introduced by Dr John Hopkinson, and consisted in making a fixed charge per quarter, proportioned to the greatest rate of supply the consumer would ever take, and a charge by meter for the actual units consumed. According to the *Electrical Review's* list of electricity supply works of the United Kingdom, 14th July 1905, a mixed maximum demand and sliding scale system is now in vogue.

The Maximum Demand System.—The maximum demand system was initiated at Brighton by Mr Arthur Wright, and is known as the 'Wright' maximum demand, or the 'Brighton,' system of charging. It is in use in many other supply stations, in a large number of which, however, it is not used exclusively. The principle of the method is that laid down by Dr Hopkinson, and consists in charging the consumer two prices, of which the one is dependent on the preparation costs, and the other on the production costs incurred by the station in supplying him. The preparation costs vary directly with his maximum demand, *i.e.* with his greatest rate of taking electrical energy during any time. For the purpose of ascertaining his demand, an instrument called a maximum demand indicator is placed in the main circuit with the meter proper, which registers in the ordinary manner the total units consumed. The Wright maximum demand indicator and other instruments of this class are described in Chapter XII. The demand indicator measures the maximum current taken by the installation. On the scale of the instrument, not only is this maximum current given, but the units consumed per quarter, or during any other period, are indicated on the assumption that the demand has been taken for one hour (or more) per day throughout the time chosen. On account of the time-lag, or sluggishness of action of these instruments, slight increases of current of very short duration or momentary short-circuit currents do not produce abnormal registrations.

The charge on this system is best expressed in the form of an equation, as follows :—

$$C = p_1 D + p_2 L,$$

where C = total amount of bill for the quarter ;
p_1 = price per maximum demand unit ;
p_2 = price per unit for those units in excess of the maximum demand units ;
D = total maximum demand units consumed during the quarter ;
$L = U - D$; and
U = total units consumed in the quarter, as registered by the meter proper.

If K denote the maximum demand in kilowatts, n the number of hours per

day during which the maximum demand is assumed to be used, then, taking a quarter of ninety-one days,

$$D = 91.n.K.$$

The maximum demand K in kilowatts is readily estimated from the maximum current A given by the demand indicator. If V be the supply voltage, then

$$K = \frac{A.V}{1000}.$$

As already mentioned, the demand units D corresponding to the maximum currents A are directly obtainable from the demand indicator. At Brighton the charge per maximum demand unit is 8d., the duration of the demand per day is taken at one hour, and a low charge of only 1d. per unit is made for all units consumed in excess of the demand units. Taking a consumption of 1000 units in a quarter of ninety-one days, and assuming that the maximum demand from the indicator is 6 kilowatts, the amount chargeable to the consumer is readily calculated. Using the Brighton charges, then

$$p_1 = 8\text{d.}\ ;\ p_2 = 1\text{d.}\ ;\ n = 1\ ;\ U = 1000\ ;\ K = 6.$$

So that $D = 91 \times 1 \times 6 = 546$ demand units.

Also $L = 1000 - 546 = 454$ low price units.

Now $C = p_1 D + p_2 L$,

$\therefore$ $C = 8 \times 546 + 1 \times 454$ pence

$= £20$, 1s. 10d.

The account will amount to £20, 1s. 10d., or at a rate of 4·8 pence per unit approximately. By giving K different values, the effect of this system of charging and the encouragement it gives to the long-hour consumer will be at once appreciated. The great advantage of the 'Wright' method of charging, when applied to purely lighting circuits, is that it secures equitable treatment to all consumers and greatly improves the load factor of the station. When, however, the system of supply is for lighting and power, or other day loads, a pure maximum demand tariff is no longer applicable, the objection to it being that it does not discriminate between day and night loads, and, further, it does not take into account the actual duration of the demand. For purely lighting loads the first part of this objection no longer holds, as the maximum demands on lighting circuits occur very approximately at the same time.

With reference to the utilisation of electrical energy for power, heating, or other domestic work during the day, Mr Wright * suggests the use of a Kapp two-rate meter system with a time-switch and a demand indicator, the latter instrument being inserted during the evening peak loads only. This combination of the Kapp and Wright systems is in use at Brighton and in other towns. A disadvantage urged against the 'Wright' method of charging is, that the average consumer experiences considerable difficulty in understanding it, and the attitude of the consumer cannot be ignored. This objection can, however, be raised, to a more or less extent, against any special tariff system which is not of the simple order of a uniform tariff, or a sliding scale based on the quantity of units consumed.

The Step-tariff System.—A very interesting tariff system is the step-

* "Some Principles underlying the Profitable Sale of Electricity," *Journal of the Institution of Electrical Engineers*, 1902, part 155, vol. xxxi.

tariff introduced by Dr Kallmann, City Electrical Engineer of Berlin, to whom the author is indebted for the particulars of the same. The principle of the system is that a certain number of units must be consumed before a rebate is allowed. So far, it does not differ from the ordinary uniform tariff with discounts, the distinction being, however, that it differentiates between the units consumed when the load is high and those when the load is relatively small. It takes into account not only the time at which the current is taken but also the duration of the demand; and the discount allowed depends on two factors—the duration and the degree of the load. For this purpose the consumer's load is divided into regions or steps. Taking a two-step-tariff system, the one region embraces the consumption when the load is light, below $33\frac{1}{3}$ per cent. of the maximum possible load of the installation, and the second step includes the consumption due to all loads above this value. A watt-hour meter, giving the total units consumed, is used in conjunction with a step-tariff instrument, which indicates separately those units which are consumed when the load has exceeded $33\frac{1}{3}$ per cent. of the maximum. When the load falls below this limit the step-tariff instrument automatically ceases to register. Such a step-tariff combination is illustrated and described in Chapter XII.

Fig. 211 represents diagrammatically an average load curve of a station for the summer months, and Fig. 212 is a diagram of a similar curve for the winter months, the abscissæ denoting the hours during the day, and the ordinates the percentage loads. Each curve, taking a two-step-tariff system with $33\frac{1}{3}$ per cent. full load as the limiting load, is divided into two steps, the bottom region, I., in which are the loads below $33\frac{1}{3}$ per cent. full load, and the top region, II., in which the loads exceed this value; further, the two steps are differently shaded, so that the consumptions in each region will be readily observed. The method of determining the rebate will be best followed from an example. Taking an installation comprising 25–16 c.p. lamps at 100 volts pressure, the maximum current, allowing 60 watts per lamp, is 15 amperes, and the maximum load is 1·5 kilowatts. The step-tariff instrument is regulated to start registering the units at, say, $33\frac{1}{3}$ per cent. of the maximum load, *i.e.* with 5 amperes in this example. Suppose that a rebate is allowed of 1 per cent. up to a maximum of 50 per cent. on each consumption in both the top and the bottom regions, reckoned on a 20 hours' demand in each. This interval of 20 hours' demand will, therefore, correspond in the top region to $20 \times 1{\cdot}5 = 30$ units, whereas in the bottom region it is one-third of this amount, *i.e.* $20 \times \frac{1}{3} \times 1{\cdot}5 = 10$ units.

The consumer will, therefore, be given a rebate of 1 per cent. on the consumption for every 10 units taken in the bottom region and for every 30 units in the top region. Taking a total annual consumption of 900 units as given by the watt-hour meter, a price per unit of 7d., and assuming that the units consumed in the top portion, as indicated by the step-tariff instrument, are 400, then the units consumed in the bottom region will be 500. The percentage discount is then (I.) in the bottom region $\frac{500}{10} = 50$ per cent., and (II.) in the top region it is $\frac{400}{30} = 13$ per cent. approximately. The cost of the total consumption of 900 units at 7d. per unit is £26, 5s. The rebate allowable is in (I.) $\frac{50}{100} \times 500 \times 7\text{d.} =$ £6, 9s. 2d., and in (II.) $\frac{13}{100} \times 400 \times 7\text{d.} =$ £1, 10s. 4d., the total rebate being £7, 19s. 6d. The amount of the bill is, therefore, £26, 5s., less £7, 19s. 6d., *i.e.* £18, 5s. 6d., and the average price per unit works out at 4·87 pence. The duration of the demand in the bottom region on this basis is 1000 hours, and in the top region is 266 hours.

The above example shows that a consumer who has used the major part of his current consumption at a low rate, and has in this manner kept his load steady over a long period, will obtain an equivalent rebate, which, further, allows him to occasionally burn all his lamps without unduly increasing the cost. An advantage of the system is, therefore, that the price for current for the whole consumption is not increased by the fact of the maximum current of the installation being reached once or twice, as only those units due to the heavy currents are reckoned at the high price per unit. A long-hour consumer in the bottom region, despite a relatively small consumption, will obtain his current at a low price per unit, and the electricity undertaking will make a fair profit, although the percentage discount appears abnormally high, because

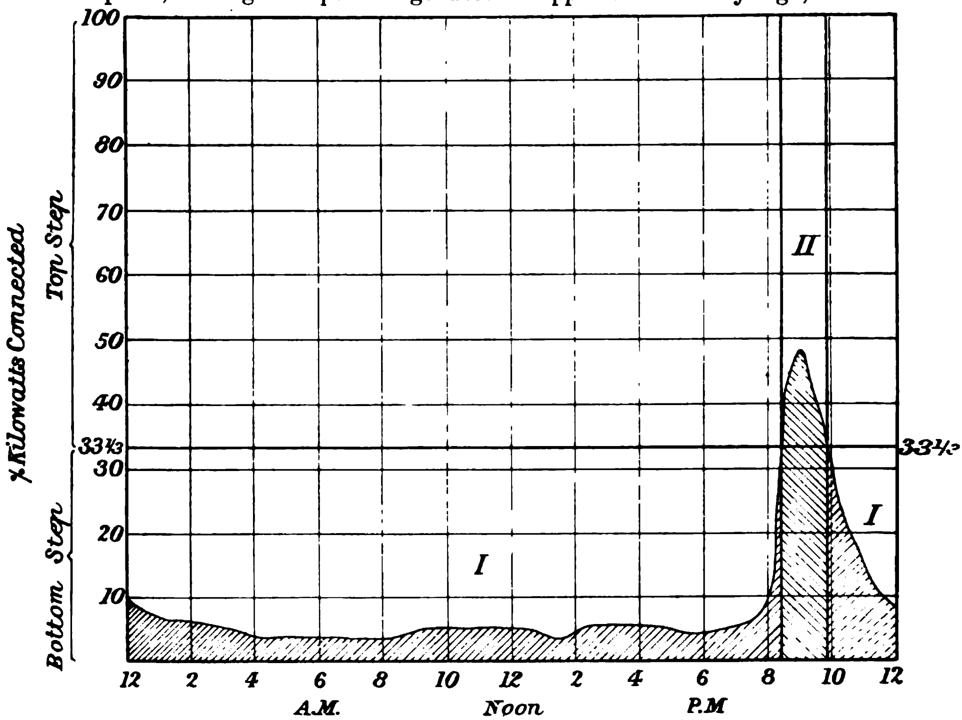

FIG. 211.

the actual rebate expressed in £ *s.* *d.* is small, owing to the average load (up to one-third of the maximum) being small. The rate of discount, the step limits (*i.e.* 33⅓ per cent., or 40 per cent., etc.), and the duration of the demand (20 hours or more) must, of course, be decided upon by the station to suit the requirements of the case.

The system practically amounts to the same thing as obtaining an average load curve of a consumer by means of a recording wattmeter, and dividing this load curve into a series of steps, or regions, and arranging the rebates on the consumption in each step in a manner analogous to that explained in the above example, the rate of discount decreasing as the load increases in steps towards the maximum. It may be as well to point out here that a difference should be made in the discounts in the summer and winter

months, as otherwise, referring to Fig. 211, the summer consumption would almost entirely be in step I., and too large a discount would be obtained.

The 'Halle' Tariff System.—In the tariff system devised by A. Jung,* Engineer and Manager of the Municipal Electricity Works at Halle, on the Saale, Germany, an hour meter is used with a meter proper. The watt-hour meter registers in the ordinary manner the total units consumed, whereas the hour meter indicates only those hours during which the current is at least half of that corresponding to the maximum number of lamps, or horse-power, in regular daily use. The tariff is independent of the size of the installation and of the actual consumption, thus placing both large and small consumers on

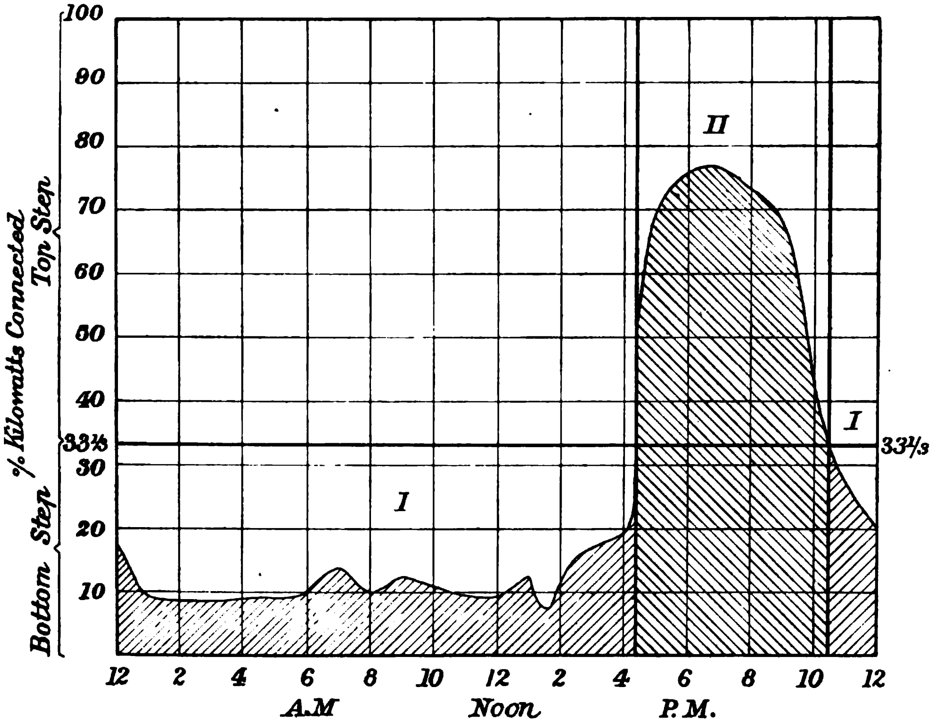

Fig. 212.

the same footing. It is based entirely on the length of time of the consumer's use of current during the year.

In the financial year (April 1 to March 31) a standard price per unit is made for those units which are consumed during a certain number of hours determined by the hour meter, whereas all other units in excess of this amount consumed in the same financial year are charged at a reduced rate.

The charges at Halle are as follows :—

1. For *lighting*, the price per unit is 60 pfennige (7·2 pence) for all units consumed during the first 300 hours given by the hour meter, whereas it is 20 pfennige (2·4 pence) per unit for all units in excess of this amount.

* The author takes this opportunity of expressing his indebtedness to Mr Jung for the details of his interesting tariff system.

II. For *power*, *heating, and other technical purposes*, the price per unit during the first 300 hours given by the hour meter is 20 pfennige (2·4 pence), and above this the rate is 10 pfennige (1·2 pence).

In the above, 1 shilling (12 pence) is taken as the equivalent of 1 Mark (100 Pfennige).

It may be of interest to state here that the power tariff applies to electric motors driving dynamos for lighting in connection with—

(*a*) a battery of accumulators of at least the same output as the dynamo during two hours;

(*b*) a power installation of at least the same output as the motor.

The station supplies either direct current at 220 and 440 volts pressure, or three-phase currents at 220, 500, and 3000 volts, and 50 cycles per second.

In order to show the effect of the tariff for the different classes of consumers, especially large and small consumers, the following tables have been prepared. For this purpose a few of the consumers connected to the station have been taken at random, and their payments given for the financial year 1904 on the basis of the meter readings.

A. *Power Consumers.*

Class of Consumer.	H.P. Connected.	Annual Consumption in Kilowatt-hours.	Annual Amount Paid.				Average Annual Price per Kilowatt-hour.	
			Mark.	£	*s.*	*d.*	Pfennige.	Pence.
Small . .	1	1,339	150	7	10	0	11·2	1·34
Medium . .	5	3,852	426	21	6	0	11·0	1·32
Larger . .	25	22,572	2523	126	3	0	11·2	1·34

B. *Lighting Consumers.*

Class of Consumer.		Number of Connections in 16 c.p. Lamps.	Annual Consumption in Kilowatt-hours.	Annual Amount Paid.				Average Annual Price per Kilowatt-hour.	
				Mark.	£	*s.*	*d.*	Pfennige.	Pence.
Shops.	Small .	6	242	77·6	3	17	7	32·0	3·84
	Medium .	24	1,118	376·0	18	16	0	33·7	4·04
	Larger .	300	7,604	2433·0	121	13	0	32·0	3·84
Private Houses.	Small .	10	416·2	119·5	5	19	6	28·8	3·46 app.
	Medium .	67	1,141·0	350·0	17	10	0	30·7	3·68
	Larger .	130	1,742·0	494·0	24	14	0	28·3	3·40 app.
Hotels & Public-houses.	Small .	6	584·0	128·3	6	8	3½	22·0	2·64
	Medium .	32	4,893·8	1179·0	58	19	0	24·1	2·89
	Larger .	165	13,342·0	3194·0	159	14	0	24·0	2·88

The above tables show very conclusively that with this tariff the small consumer is equitably treated with the large consumer. Moreover, both for light and power, current is supplied from the Halle electricity works, on an average, 40 per cent. cheaper than from any other station in Germany.

The system has been so successful that, despite the low prices charged, the station, in consequence of its rapid growth, obtained in the fourth year of its working a gross surplus of more than 9 per cent. of the total capital outlay for interest, depreciation, and other charges, after deducting direct working costs. The capital expended amounted to 4¼ million marks, *i.e.* £212,500, and the number of connections in the fourth year was equivalent in round figures to 4500 kilowatts.

In this system the consumer pays the high rate per unit during the financial year until the hour meter has registered 300 hours, when all units afterwards are charged at the low price.

The hour meter is not set to the capacity of the installation, but in each installation the maximum number of lamps, or horse-power, in regular daily use is determined, and the hour meter is then set to half this amount. In other words, the hour meter is so adjusted that it registers the hours during which the current has a value equal to (and naturally in excess of) that corresponding to half the maximum number of lamps, or horse-power, in regular daily use.

Taking a house, for example, in which 60 lamps are installed and in which the maximum number in regular daily use is 6, the hour meter is set to register with 3 lamps, so that the consumer will reach the hours required with 3 lamps in use. He can, if he so desire, obtain his current at a relatively cheap price by keeping only 3 lamps burning during the 300 hours. Afterwards, for the remainder of the financial year, he can burn more or fewer than the 3 lamps, as he is then no longer bound to any number. The consumer has, therefore, only to watch the hour meter until he has reached the 300 hours. As the hour meter is in each case set to half the recurring maximum daily used by the consumer, each consumer will obtain current at a low price provided his yearly use of current extends for longer than the 300 hours.

If a consumer does not reach the 300 hours during the financial year, he has to pay for all the units he consumes during this year at the high rate. A case of this sort rarely, or never, happens, as the 300 hours are reached by all the different classes of consumers. For instance, offices take current during the year for about 400 hours, shops for about 700 hours, hotels and public-houses for about 2000 hours, and private houses for about 1200 hours. Power consumers who take current daily for one hour and longer also reach the 300 hours, as in their case, too, the hour meter is set to half the maximum horse-power in regular daily use (not half the maximum installed), and the average horse-power is above this amount. The results obtained with this tariff are very satisfactory, and it has the advantage of simplicity, and of being easily understood by the average consumer.

The Two-rate System. — In a two-rate, or double-tariff, system, two distinct charges are made, based on the time of day when current is taken. During the heavy-load periods on the station in the evening a high rate per unit is charged, whereas a low charge per unit is made for the units consumed during the rest of the day, irrespective of the use of the supply during either period. In order to determine the amounts of the two consumptions, a two-rate, or double-tariff, meter is used. It consists, in

general, of an ordinary meter fitted with two distinct registering dials, one for the high-priced and the other for the low-priced units. By means of a change-over device attached to the register and actuated by a time switch, or double-tariff clock, the rotations of the meter spindle are transferred to one or other of the two integrating mechanisms, according to the time of day as set on the clock. The units given on the one dial will be the consumption during the low rate, or ordinary rate, periods of the quarter, and those on the second dial will be the consumption at the evening rate, when the station is working in the region of the peak. The sum of the two dial readings is the total consumption. The tariff time can be varied in a very simple manner with the time of year by the station, so that the period of the high evening rate is longer in the winter than in the summer. The account is readily made out, and it is easily understood by the consumer, who can check his consumptions at the two rates from the two separate readings of the meter dials. By means of a suitable index, attached to the meter register, he is further able to at once see at which tariff he is taking current. This system appears to answer very well the present-day requirements peculiar to electricity supply. It encourages the general use of electricity and the long-hour consumer. It is automatic and reliable, provided suitable two-rate meters be employed, many examples of which will be found described in Chapter XII.

It may be as well to point out here that there are two classes of double-tariff meters. In the one class the time switch is combined with the meter proper, forming with it one complete instrument, and mechanically operates the change-over device of the counting trains. In the other class the time switch is supplied as a distinct piece of apparatus, and electrically actuates the change-over mechanism of the integrating gears. The only modification of the meter proper is, in general, in connection with the register.

In some two-rate systems the time switch introduces resistance into the armature circuit of the meter during the periods of the low or ordinary rate, so that the speed of the meter is reduced, and in the ratio of the low to the high tariff. During the high-rate time the speed of the meter is the normal speed, the resistance being then automatically cut out. For instance, if the high rate be 6d. per unit and the low rate be 2d., the speed is reduced to one-third of what it would be under normal conditions. The product of the units given by the meter and the high-rate charge per unit (in this particular case 6d.) will be the amount of the consumer's account. The great disadvantage of this method is, that the units registered by the meter are not the actual units consumed, so that a record of the actual consumption cannot be made.

The Prepayment System.—In this system of charging the consumer pays for his energy before he actually uses it. For this purpose an automatic slot meter is used. The object is to reach the class of consumer who is either unable or unwilling to run up a quarterly account, but is very profitable to the company. The supply undertaking with this system incurs no bad debts, the amount of clerical work of the meter department is considerably minimised, and the load is usually a steady long-hour one. The price per unit is necessarily high, to cover the meter rentals, which cannot be separately charged, and which are heavier than for an ordinary meter. The consumer, however, enjoys the benefit of obtaining a commodity on a convenient payment system.

The Hour Meter System.—In many small installations and in certain circuits the load is constant, or very approximately so, and it is then only

necessary to measure the hours of supply to determine the units from the known value of the load. It generally happens in such cases that the amount of the consumption hardly warrants the installation of a relatively costly meter, and an hour meter is then used. The hour meter registers the number of hours during which current flows in the circuit, and stops when current is not taken. It is a simple and cheap piece of apparatus, consisting of a clock which is actuated by the current. It is employed in connection with ordinary meters in special tariff systems, in which the discounts, or charges, are based on the time during which current is taken, and more particularly when that current is in excess of a predetermined amount. The hour meter is slightly modified for different purposes, and many combinations can be obtained with it. For public lighting work, the price for which is generally at a fixed rate per lamp per year, an hour meter may be useful for ascertaining the exact number of hours of lighting in each case.

LIST OF PAPERS ON SYSTEMS OF CHARGING.

1892.

HOPKINSON, Dr JOHN, "The Cost of Electricity Supply," *The Junior Engineering Society*, Nov. 4. Also *El. Rev.*, vol. xxxi. p. 571.

KENNEDY, Sir ALEX. B. W., "The Cost of Electricity Supply," *El. Rev.*, vol. xxxi. p. 683.

HOLMES, A. BROMLEY, "The Cost of Electricity Supply," *El. Rev.*, vol. xxxi. p. 716.

1894.

GIBBINGS, ALFRED H., "Various Methods for Charging the Public for Electricity from a Central Station," *El. Rev.*, vol. xxxv. pp. 96, 125, 157.

KAPP, GISBERT, "Entwickelung und Lage der englischen Elektrotechnik," *E.T.Z.*, p. 311.

1895.

RASCH, Dr, "Ein Beitrag zur Herabsetzung des Stromtarifs," *E.T.Z.*, p. 739.

1896.

MAYCOCK, W. PERREN, "The Wright System," *El. Rev.*, vol. xxxviii. p. 261.

1897.

KALLMANN, Dr M., "Die Stromtarife bei Elektricitätswerken und die Konkurrenz der Blockstationen," *E.T.Z.*, Heft 16.

1898.

CLAUDE, G., "La Tarification de l'Énergie Électrique," *Écl. Élec.*, vol. xiv. pp. 93–96.

BARSTOW, W. S., "Charging for Electrical Energy," *El. Eng.*, N.Y., vol. xxv. pp. 49–51.

Oxley, E., "Multiple Rate Metering," *El. Eng.*, N.Y., vol. xxv. pp. 51–55.
Dow, A., "Electric Lighting for Profit," *El. Rev.*, N.Y., vol. xxxii.
Turner, M. E., "Cost of Electrical Energy," *El. World*, vol. xxxii. pp. 209, 210.
Meynier, A., "La Tarification de l'Énergie Électrique des Stations Centrales," *Ind. Élec.*, vol. vii. p. 507.
Arnot, W., "Meters and Systems of Charging for Electrical Energy," *El. Eng.*, vol. xxxii. pp. 716–719.

1899.

Debbell, E. L., "Systems of Meter Rates," *Electricity*, N.Y., vol. xvi. pp. 101, 102.
Wilkens, K., "Bemerkungen zur Tariffrage bei Elektricitätswerken," *E.T.Z.*, Heft 20.

1901.

Hohmann, Ed., "Das Wright'sche Stromtarifsystem," *E.T.Z.*, Heft 34.
Kallmann, Dr M., "Verbrauchs-Stufenmesser und selbstthätige Staffel-Tarifanzeiger," *E.T.Z.*, Heft 34.
Wilkens, K., "Die Bemessung des Strompreises bei Elektricitätswerken," *E.T.Z.*, p. 116.
Fodor, E. de, "Zur Tariffrage," *E.T.Z.*, pp. 184, 187.
Ross, F., "Bemessung des Strompreises bei Elektricitätswerken," *E.T.Z.*, p. 209.

1902.

Wright, Arthur, "Some Principles underlying the Profitable Sale of Electricity," *Proc. Inst. El. Eng.*, part 155, vol. xxxi.
Lauriol, P., "La Tarification de l'Énergie Électrique," *Écl. Élec.*, vol. xxxiii.
——— "Central Station Charging and Rates in Use in U.S.A," *El. World and Engineer.*

1903.

Crapper, E. H., "Methods of Charging for Electrical Energy," *Electrician*, vol. lii. p. 330.
Perry, F. B., "A Method of Determining Prices and Rates for Electrical Power," *El. Rev.*, N.Y., vol. xliii. p. 885.

1904.

Ponseel, A., "Études d'Économie Industrielle à l'Usage des Usines d'Électricité," *Électricien*, vol. xxvii.
——— "Methods of Charging for Electrical Energy," *El. Rev.*, vol. liv. p. 5.

1905.

Taylor, A. M., "Stand-By Charges, and Motor Load Development," *Proc. Inst. of El. Eng.*, vol xxxv. part 174, p. 227. Also *El. Rev.*, vol. lvi. pp. 76, 85, 785.
——— "On the Diversity Factor, and its Influence on Motor Load Charges," *El. Rev.*, vol. lvi. p. 1011.

SHEFFIELD, T. W., "On Commercial Management of Municipal Electric Supply," *El. Rev.*, vol. lvi. p. 993.

——— "Some Methods of Charging for Electric Supply," *El. Rev.*, vol. lvi. p. 1039.

KILGOUR, HAMILTON, "Notes on Costs and Tariffs for Electricity Supply," *Proc. Municipal Electrical Association, and El. Rev.*, vol. lvii. p. 78.

SILLAR, A. R., "Free Wiring and Prepayment Meters," *Proc. Municipal Electrical Association, and El. Rev.*, lvii. p. 78.

RICHARDSON, H., "Dundee Power Supply (The Equitable System of Charging for Electric Energy)," *El. Eng.*, vol. xxxv. pp. 476–478.

ABBREVIATIONS.

El. Rev. = Electrical Review, London.
El. Rev., N.Y. = Electrical Review, New York.
El. Eng. = Electrical Engineer, London.
El. Eng., N.Y. = Electrical Engineer, New York.
Écl. Élec. = Éclairage Électrique.
Ind. Élec. = Industrie Électrique.
E.T.Z. = Elektrotechnische Zeitschrift.
Proc. Inst. El. Eng. = Proceedings of the Institution of Electrical Engineers.

CHAPTER XI.

PREPAYMENT METERS.

General Description—Beaumont Prepayment Meter—British Thomson-Houston Prepayment Meter—Vulcan Prepayment Meter—Fort Wayne Prepayment Meters—Hookham Prepayment Meter—Mordey-Fricker Prepayment Meter—Reason Prepayment Meter—Prepayment Meter of General Electric Co., U.S.A.—Prepayment Meter of the Compagnie pour la Fabrication des Compteurs, Paris—Watson Prepayment Meter.

General Description.—A very large field exists for a cheap and reliable prepayment electricity meter, and most of the well-known meter manufacturers are at the present time engaged in perfecting their different types, which in many cases have not passed beyond the experimental stage. By the aid of the prepayment meter a central station can profitably supply current to the small consumer whose actual consumption is insufficient to cover the cost of keeping the account. The consumer's convenience is served by this method of charging, and no risk of non-payment is incurred by the supply company.

A prepayment electricity meter generally consists of two distinct parts, viz. the prepayment device and the meter proper, the two being either mechanically or electrically combined. The prepayment or automatic slot attachment is a mechanical arrangement which, on the insertion of a coin of the right denomination, can be actuated in such a manner that a main circuit switch is closed, and either a spring controlling a clockwork train of wheels is wound up, or some other mechanism is displaced to a predetermined extent. The meter proper does not materially differ from the type to which it belongs, and, in general, the register is the only part of the meter which is modified. When the main circuit switch of the prepayment device has been closed on the insertion of the first coin, current can be taken, and the meter, if of the motor type, revolves in the usual way, and in so doing allows the prepayment device to return to its normal condition. The rate at which this is arrived at depends on the current flowing and on the amount of energy represented by the value of the coin inserted. When the amount of energy corresponding to the coin has been consumed, the main switch of the prepayment attachment is automatically opened, and no more current can then be taken until a further prepayment has been made. In general, several coins can be successively inserted, the number differing in the different types, and when this number has been reached a locking arrangement comes into action, by means of which a further prepayment cannot be made until one coin's worth of energy has been consumed.

The important point to be remembered in connection with prepayment meters is, that the restoration of the automatic mechanism to its normal condition should not cause additional work to be performed by the meter, as,

otherwise, its accuracy and its light load registration will be impaired. It is not possible to comply with this condition absolutely, but the extra work involved by the prepayment attachment should be reduced to a minimum; it should be invariable in character, *i.e.* independent of the number of coins inserted, and the driving torque of the meter should be correspondingly increased. The prepayment attachment should, moreover, not materially increase the cost, which at the present is too high, and is the cause of the comparatively restricted use of this type of meter. It is highly essential that the full amount of energy represented by a coin should be obtained after its insertion, that it should not be possible to obtain more than this amount of energy for one coin, and that every precaution should be taken to prevent damaged coins, pieces of wire, or coins of the wrong denomination to be inserted in the slot and actuate the prepayment mechanism.

The meter should not only show in the usual manner the units consumed, but the number of coins standing to the credit of the consumer, so that he can always tell when prepayment has to be made without waiting until current is interrupted. It is also valuable for the total number of coins inserted to be registered, as this affords a check on the collector.

Beaumont Prepayment Meter.—The prepayment device invented by Mr F. J. Beaumont is a very simple and effective coin-freed mechanism, which can be easily attached to any type of motor meter. It embodies many important features. A special compound differential gear is used, which causes a hollow worm to travel longitudinally along a horizontal axis through a predetermined distance when a coin has been inserted in the operating mechanism. On the passage of a current this worm is returned to its original position by the armature spindle of the meter, when the instrument switch is opened. To prevent irregular movements of the coin-freed mechanism by any unsteady or sudden action of the handle rotating the coin, the mechanism is not directly actuated by the coin itself, but is operated on the discharge of the coin into the coin till.

Distinct from most devices of this type, the change from one price per unit to another is readily effected by simply raising or lowering a price changer screw, which can be done with the meter *in situ*. In all other forms the meter has to be partially dismantled to allow a new change wheel, or set of change wheels, to be introduced to meet the required change in the tariff.

Before the instrument switch is opened by the action of the meter, a 'dimming' resistance is automatically thrown into the main circuit, causing the lamps to burn dull, and in this manner an effective warning is given that the light will shortly be cut off. This resistance is in circuit just long enough to enable a further prepayment to be made, if desired, without an interruption of the supply.

The general arrangement and operation of the prepayment attachment will be understood by reference to Figs. 213 to 215, which represent three different views of the device in connection with a continuous current watt-hour meter, and to Fig. 216, which shows more in detail the construction of the compound differential gear. The coin C is first inserted in the slot in the meter case, from which it falls into the recess in the coin carrier W, and the handle H is then turned. This action of the handle rotates the carrier W, and causes the coin to describe the circular dotted path shown in Fig. 214, in the course of which the coin depresses the toe T of the actuating lever L, pivoted at O_1, the other end of which is correspondingly raised. The coin next strikes against the stop S and discharges into the coin till Z. The lever

L is now free to move, and is returned by the spring Y into its original position, in which it rests on the price changer screw E. During the return motion of the actuating lever the pawl P attached to it engages with the ratchet wheel R, and rotates it through an amount corresponding to the value of the coin inserted. The rotation of the ratchet wheel R causes the hollow worm U to rotate in the opposite direction and travel along the axis A, in a

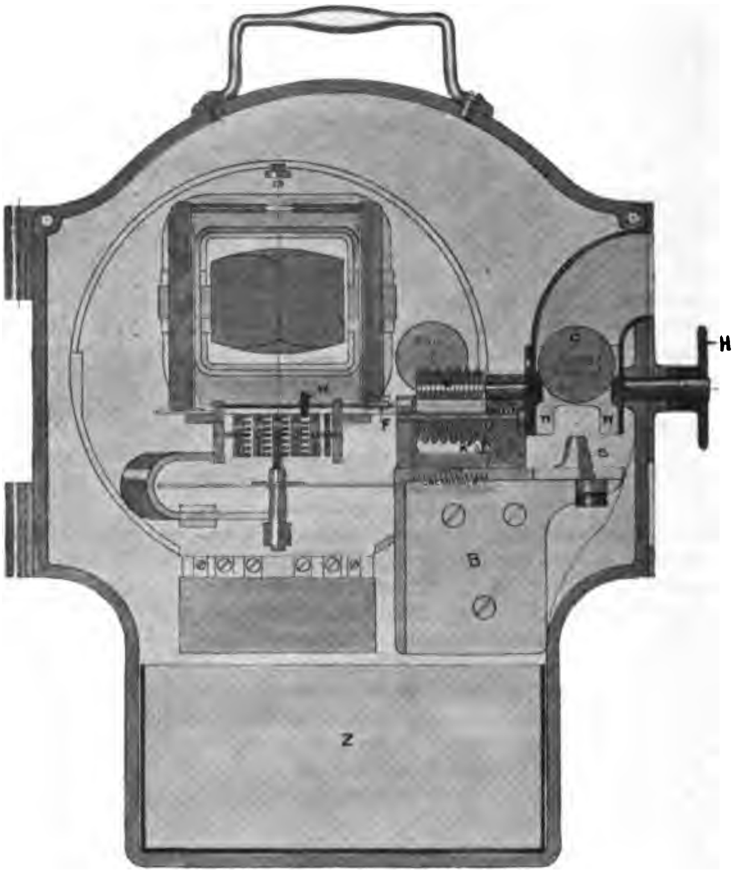

FIG. 213.

manner to be explained later. This worm U carries at one end two pins P_1 and P'_1, by means of which the switch arm G is actuated and the mercury switch opened and closed.

The switch arm G is pivoted at O_2, and is provided with two projections V_1 and V_2. The ratchet wheel R is revolved clockwise, as already explained, each time a coin is inserted, and the hollow worm U is turned counter-clockwise. When this happens on the insertion of the first coin, the pin P'_1 engages with the projection V_1 and tilts the bar G into the position shown in Fig. 214, causing the plunger attached to the end M of the switch arm G

to enter the mercury cup of the mercury switch, and the circuit is then closed. Under the action of the meter the worm U is rotated back, and, when it has nearly reached the end of its travel, the pin P_1 raises the switch arm G, the end N of which forces back the quick-break lever L_1, pivoted at O_1, allowing the pin P_2 attached to this lever to enter the middle groove.

The plunger is slightly raised out of the mercury cup by this action, and

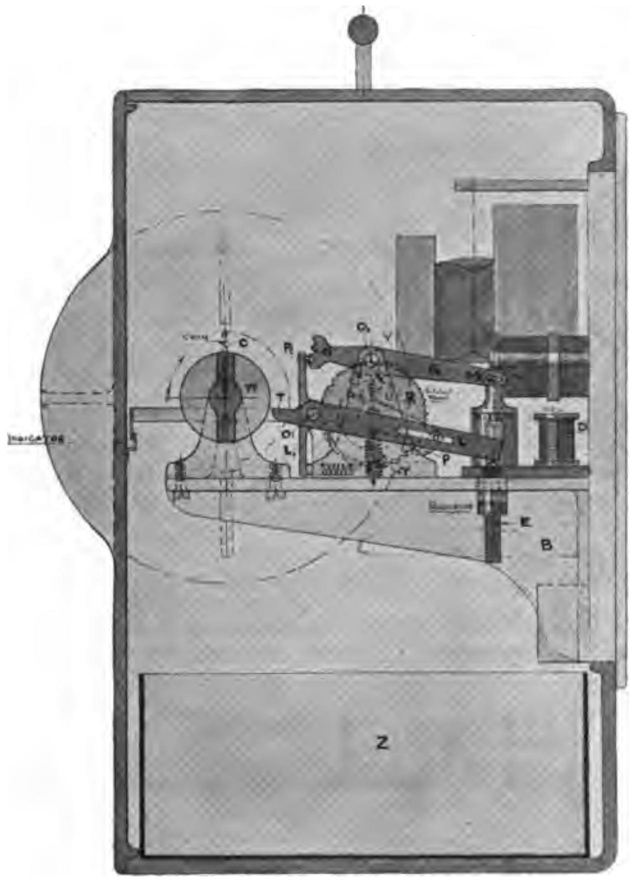

FIG. 214.

the dimming resistance D is automatically inserted in the circuit in the following manner. The plunger has two contacts, one slightly above the other, the two contacts being connected through the dimming resistance D. When the plunger is completely immersed in the mercury bath this resistance is short-circuited on itself; when, however, it is slightly raised, the upper contact is above the mercury, so that the current now flows from the mercury through the lower contact to the dimming resistance, from which it passes to the lamps, which now burn dull. The switch arm G is held in this position, with the pin P_2 of the quick-break lever L_1 in the middle groove at

N until, as the worm U continues to rotate, it is tilted further by the pin P_1' now coming into action. In consequence, the pin P_2 is made to enter the top groove at N, and the circuit is rapidly and completely opened.

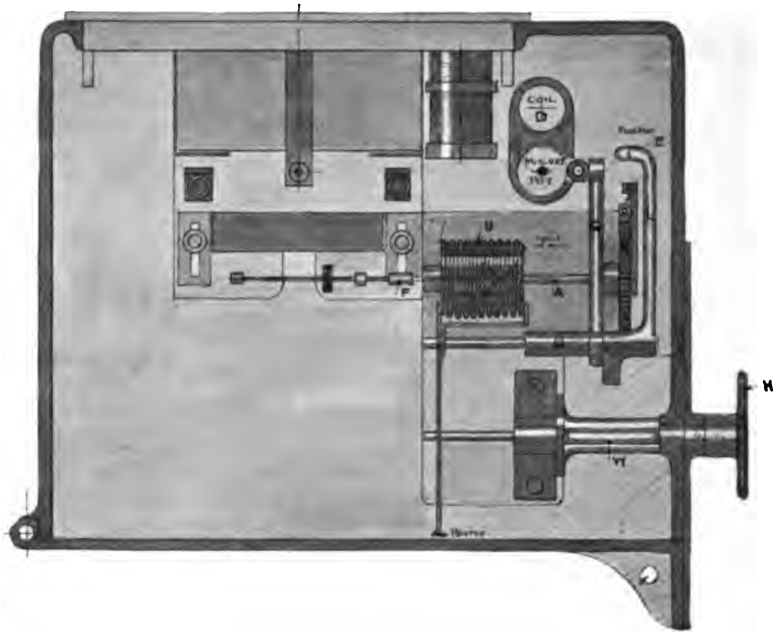

Fig. 215.

It will be seen that after the coin has been discharged the actuating lever L is returned by the spring Y through a certain distance, limited by the

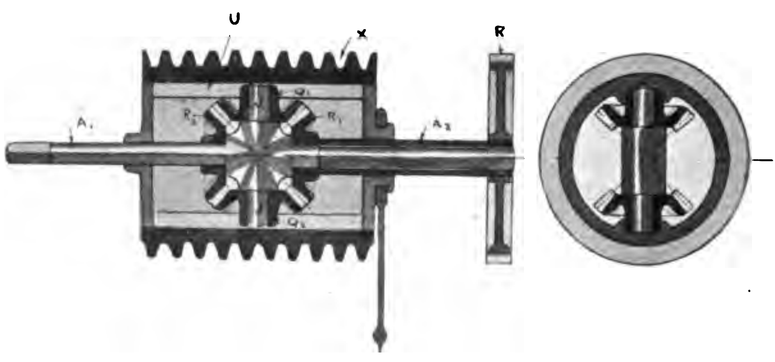

Fig. 216.

position of the price-changer E. This distance determines the limit of rotation of the ratchet wheel R per coin inserted, and is dependent on the price per unit. By raising or lowering the screw E the vertical drop of the lever L is altered, and this change is the only one necessary when an

alteration in the tariff is made. At the same time as the handle H is rotated on the insertion of a coin a shutter is turned, so that a second coin cannot be inserted until the slot in the shutter again coincides with that in the meter cover after the first coin has been discharged. When the number of coins for which the meter is set has been inserted, the shutter is locked in position, and a further prepayment cannot be made until at least one coin's worth of energy has been consumed.

The manner in which the compound differential gear produces the desired motion of the worm U will be followed from the drawing in Fig. 216. The ratchet wheel R is rotated, as explained above, by the actuating lever L (Fig. 214), and in turn drives the mitre wheel R_1, which together with the other wheels R_2, Q_1, and Q_2 forms the compound differential gear. When the wheel R_1 is rotated it revolves the two idle wheels Q_1 and Q_2, which will ride over the mitre wheel R_2. The axles J J of the two wheels Q_1 and Q_2 engage in two internal grooves in the hollow worm U, so that it is caused to rotate. The worm U will also rotate, but in the opposite direction, when the mitre wheel R_2 is turned by the action of the meter, its shaft A_1 being driven by the pinion W_1 (Fig. 213), which gears either with the counting train, or meshes through an intermediate gear with the armature spindle of the meter. The rotation of the worm U is converted into a longitudinal travel in either direction by means of the fixed pin P_3 (Fig. 213), which engages with its external thread X.

The slight extra friction the meter has to overcome, due to the prepayment attachment, consists in revolving the worm U along the axis A (Fig. 215), and in opening the switch when the prepaid energy has been consumed. It will be seen that this additional retardation to the meter is constant in character, *i.e.* the friction to be overcome is independent of the number of coins inserted.

The total units consumed are given by the cyclometer counter or ordinary register of the meter proper, and the *unconsumed units* are indicated by a pointer, which is moved over a horizontal scale in either direction by the worm U, and stands at zero when the instrument switch is opened. The whole of the prepayment mechanism is self-contained on a bracket B, from which it is easily detached after the coupling F has been disconnected. The coupling F connects, through a suitable gearing, the prepayment attachment with the integrating train or armature spindle of the meter.

British Thomson-Houston Prepayment Meter.—The British Thomson-Houston Company, Rugby, use a simple prepayment device in mechanical combination with their various types of meters. In Fig. 217 is given a front view of their O'K. meter fitted with the prepayment attachment. The register is the only part of the meter proper which is modified, and is shown in detail in Figs. 218 and 219. A disc D (Fig. 218) is fixed to an axle A, supported between the side plates of the registering mechanism. This disc is actuated by the insertion of a coin, in a manner to be explained later. It carries on its periphery a pinion D_1, which gears with the toothed wheels B and C. These wheels are loosely mounted on either side of the disc, and the one wheel B gears with the last wheel W of the integrating train of the meter. The wheel C is provided with ratchet teeth, by means of which it is rotated by the pawl P_1 (Fig. 219) attached to the actuating lever L, and by means of the pawl P_2 the wheel C can rotate in one direction only. The lever L is pivoted at E to the side plate of the registering train and is raised by the action of the coin.

The coin-freed mechanism rotates the disc D through a predetermined angle on the insertion of a coin, and simultaneously closes the switch of the instrument. It is illustrated in Figs. 220 and 221, of which Fig. 220 is a side view, with the coin drum removed for the sake of clearness; and Fig. 221 is a second side view, showing only so much of the mechanism as is necessary to explain the operation of the switch by the prepayment device. The coin drum is carried on the axle M, which is rotated by a handle external to the meter case. The drum is recessed, and the recess in the zero position is below the coin slot in the meter case. When a coin is inserted in the slot it falls into the recess in the drum and projects above it, so that on rotating the handle it engages with the lever L (Fig. 219) and raises it, causing the disc C to be rotated. As the handle is turned further the coin clears the arm L, allowing it to return by gravity to its normal position against the stop Q. The coin then drops into a coin till, and on returning the handle to its original position the slit in the coin drum is ready to receive a further coin. The coin drum and handle are prevented from being moved in the reverse direction, until the coin is dropped and the switch set, by means of the ratchet wheel R (Fig. 220) and the pawl P_3. The axle M also carries a cam N, which, on the handle being turned, rocks the U-shaped plate U round O, at which it is pivoted. The switch arm S is also pivoted at O and is held normally in the

FIG. 217.

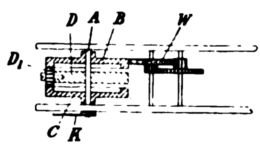

FIG. 218.

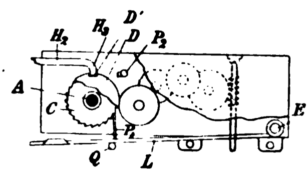

FIG. 219.

open position by means of a spring. H is a pivoted lever having two arms, of which H_1 engages with the upper end of the lever L_1, pivoted at O_1 on the switch arm. The lever L_1 is provided with a projection L_2 in the path of the U-shaped plate U. The other arm H_2 of the lever H has a tooth H_3, which in the zero position of the disc D (Fig. 219) just clears the notch D′ in the periphery of this disc.

If the handle be turned with no coin in the coin drum, the cam N rotates

the U-shaped plate U, causing it to engage with the projection L_2. This action tilts the lever H, so that the tooth H_3 enters the notch D′ in the disc D and the arm H_1 is raised. This allows the lever L_1 to turn round its pivot at O_1, and the projection L_2 moves out of the path of U. On turning the handle still more, U only rotates round O without actuating the switch S, which remains open. If, on the other hand, a coin has been inserted in the coin drum, on rotating the handle the coin raises the lever L (Fig. 219), which rotates the wheel C, causing the pinion D_1 (Fig. 218) to revolve on its axis and advance the disc D in the same direction as C through an angle corresponding to the value of the coin inserted. The notch D′ is in this manner moved clear of the tooth H_3, which now rests on the rim of the disc D. In this position the lever L_1 is prevented from turning round O_1 by the arm H_1, and its projection L_2 remains in contact with U. The latter now causes the switch arm S to

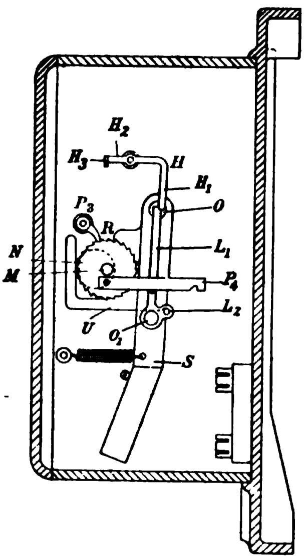

Fig. 220.

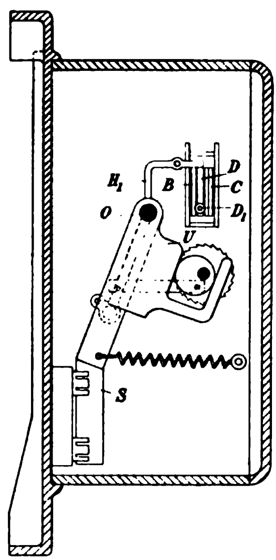

Fig. 221.

move with it, as shown in Fig. 221. When the switch is closed, it is held in the closed position by the pawl P_4, which now engages with a pin on L_1. On the passage of current through the meter, the armature rotates and drives the integrating train through the worm on its spindle. The wheel B is rotated in the opposite direction to D_1, and the wheel C is prevented from moving backwards by the pawl P_2, so that the pinion D_1 revolves on its axis and returns the disc D towards its initial position. When an amount of energy has been consumed equivalent in value to the coin, the notch D′ comes again under H_3. The lever H now moves so that the levers H_1 and L_1 are free, and the pin on L_1 is released from the pawl P_4. The spring then pulls the switch arm S out of the contacts, and the circuit is opened. By inserting several coins in succession the angle through which the disc D is turned is correspondingly increased, the switch remaining closed after the first coin has been dropped in, and coins to the number of ten may be inserted one after the other.

A feature of the arrangement is that the number of coins inserted does not increase the work the meter has to do in consequence of the prepayment attachment. The extra friction to be overcome by the meter consists in the pressure of a light arm on the rim of a revolving disc. It is constant in value, and can, therefore, be completely taken into account in the calibration of the meter. By means of a small pointer, clearly seen in the front view of the meter, Fig. 217, and marked K in Fig. 218, the coins standing to the credit of the consumer are indicated. The pointer rotates with the disc, and stands at the zero of the coin register when the switch is open.

The Vulcan Prepayment Meter.—In the Vulcan prepayment meter the prepayment attachment consists of a clockwork train of wheels driven by a mainspring and controlled by a light escapement lever, which forms the connecting link between the meter proper and the automatic device. Fig. 222 is a view of the instrument with the cover and coin till removed, showing the meter proper on the left and the prepayment part on the right.

Fig. 222.

Beneath the coin slot is a shaft which, on the insertion of a coin, can be turned by a handle, when the mainspring of the clockwork is wound up.

When the coin is inserted in the slot C (Fig. 223), it falls into a recess in the shaft and locks it with a ratchet wheel B, which can now be rotated through an angle of 45 degrees by turning the handle H. The coin will then come under the shaft and will fall into the till T.

The motion of the ratchet wheel B is transmitted through a differential gear (Fig. 224) to the driving shaft A of the clockwork, and thus winds up the mainspring R to a prearranged extent. The train of wheels *a b* (Fig. 225) terminates in an escapement, controlled by a slotted lever *g*, interlocked with the meter proper by means of a pin *h*, which is attached to a small disc on the ratio-wheel axle of the ordinary register of the meter. The pin works in the slot of the escapement lever, the alternate raising and lowering of which permit the escapement wheels to revolve. When the first coin is inserted, turning the handle not only winds up the spring, but closes the circuit switch in the instrument. As soon as current is taken by the user, the meter rotates and sets the escapement lever in motion. This allows the mainspring to unwind at a rate proportional to the rate at which energy is being consumed. The switch remains closed until the spring is unwound, when it immediately opens, and no more current can be taken without further prepayment. Successive coins to the number of eight can be inserted at one time, and at each

insertion the tension of the mainspring is proportionally increased. When the eight pennies have been dropped in, a locking lever is brought into action, which closes the slot and locks the handle until one pennyworth of energy has been consumed.

No power is transmitted between the meter proper and the prepayment device, and the only extra work performed by the meter consists in raising

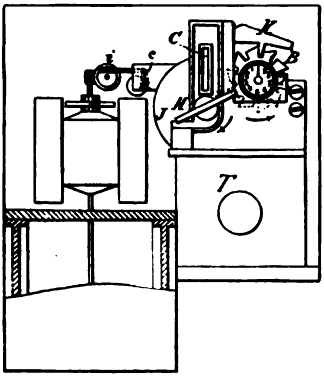

FIG. 223.

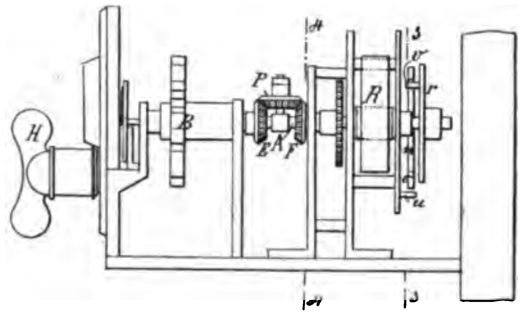

FIG. 224.

and lowering the light escapement lever. The rate at which this lever allows the spring to unwind varies with the price of the unit of electrical energy. By altering the ratio of the clockwork the instrument can be arranged to suit any price between threepence and one shilling per unit. The front plate of the prepayment part is provided with two sets of dials. The upper set consists of three pointers which indicate the number of coins which have been inserted since the meter was installed, and the lower dial shows the exact number of coins standing to the credit of the consumer. As the coins are inserted the pointer of this dial moves forward, and on the passage of a current moves back to zero, which it reaches when the circuit switch opens. The energy consumed is given on the ordinary meter dials, the reading of which, multiplied by the price per unit, should be equal to the reading of the coin register. The instrument, which is made in three sizes of 2, 3, and 5 amperes, can be used without any alteration on either a continuous or alternating current circuit. The coin till is secured by a padlock, and can be removed without unsealing the main cover.

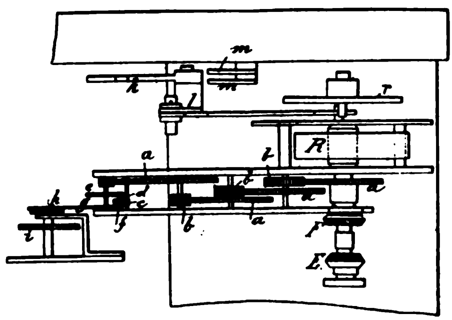

FIG. 225.

Fort Wayne Prepayment Meter.—The prepayment meter manufactured by the Fort Wayne Electric Works, Fort Wayne, Indiana, U.S.A., consists of their induction meter, type W, mechanically combined with a 'Wood' prepayment attachment. The latter is a clockwork train of wheels terminating in a

novel escapement, which is released by the operation of the meter proper. The force driving the train is obtained from a large flat coil spring inside a barrel, on the front end of which are the credit figures. The rear end of the spring barrel is covered by a disc with an internal and external gear on its rim. The external gear is controlled by the escapement, which meshes with the integrating train of the meter through a pinion connection. The internal gear is driven through an intermediate gear, which is mounted on the spring barrel and meshes with a pinion on the stud within the hollow shaft of the knob or handle of the instrument. This combination of gears is used to render the operations of the knob on the credit indicator and of the escapement independent of one another. In this manner the device will simultaneously and correctly credit and debit if a coin should happen to

FIG. 226.

be inserted coincidently with the release of the escapement in the attempt to record the consumption of another unit.

The simultaneous credit and debit would leave the credit figures unchanged. In practice this very rarely occurs, as a prepayment is usually made when the escapement is locked. The escapement is separately illustrated in Fig. 226. The pinion shaft, which is driven through the pinion gear by the integrating train, carries a small cam, which, as it revolves, oscillates an eccentric arm that rocks on its elbow. This arm moves a finger backwards and forwards across the rim of the release gear wheel in mesh with a damper fan.

The pinion makes one complete revolution during this advance and retreat motion of the finger. During the first half of the revolution the finger displaces a catch from a pin set in the rim of the release gear, and during the second half of the revolution it is withdrawn from the pin. When the finger has nearly approached its outer position the release gear is free to revolve

under the action of the mainspring through a train of three gears, of which the middle one is large, and makes a single revolution for each release. A pin on the middle gear wheel pushes the catch back into the path of the stop pin on the release gear wheel, and so arrests its motion after it has made the requisite number of revolutions to allow the spring to turn back the credit figures one place.

The general appearance of the prepayment meter, with the case on, is shown in Fig. 227.

The operation of the mechanism is simple. The coin is inserted in a slot in the hollow shaft behind the knob in front of the instrument. It fits in a slot in the stud within the shaft, and so forms a key. On turning the knob the stud will also turn, and through its pinion will rotate the intermediate gear, causing it to roll round on the internal gear of the stationary double gear disc and to carry with it the spring barrel and credit figures. This action winds up the main spring and places the coin to the credit of the consumer, as shown by the figure through the window above the knob. The knob once started, on the insertion of a coin, cannot be reversed, but must be given a half turn, when the coin falls through the tube into the coin receptacle. The instrument switch is closed on the insertion of the first coin and the subsequent operation of the knob. When current is taken, the intermediate gear is now driven by the mainspring in the opposite direction and turns back the credit figures as explained.

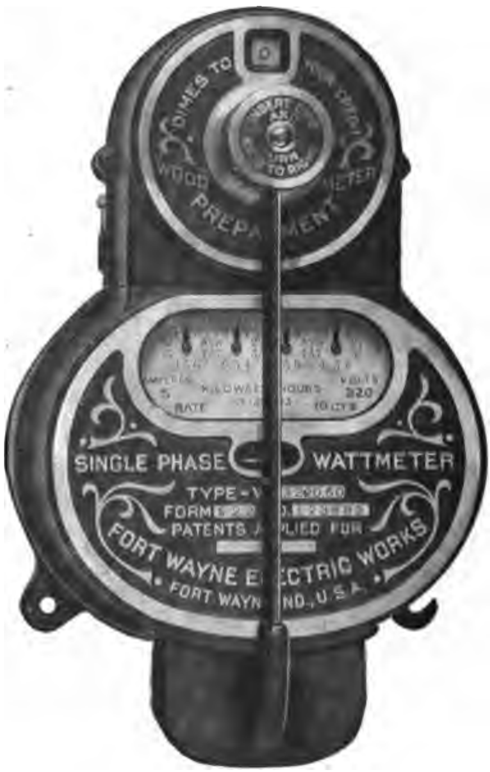

FIG. 227.

The coin used in America is the dime (10 cents), and twenty such coins can be inserted in the above manner in succession, so that prepayment can be made to the value of $2.00.

The four-point switch is opened by the last escapement when the energy consumption corresponds to the amount prepaid. A change in the tariff only affects the size of the small gear connecting the meter registering train with the escapement train, so that the meter can be readily adapted to any rate.

The escapement movement is released once for every rate unit, and the meter only moves a very small brass lever about one-eighth of an inch during this period.

In exactly the same manner as above, the Fort Wayne Electric Works

adapt their type K induction meter for a prepayment system. An internal view of this type, with the prepayment case removed, is given in Fig. 228, which clearly shows the type of instrument switch used.

For those installations requiring a separate prepayment device in positions distant from the meter, this company also supply the prepayment mechanism and coin box as a separate instrument, in electrical connection with the meter proper. The construction is exactly similar to that already explained, with the necessary modification of the tripping device. The escapement motion is released by a cam, operated by the armature of an electro-magnet within the

FIG. 228.

FIG. 229.

case of the instrument. This electro-magnet takes the place of the pinion which is driven by the registering train in the above two types. The device is electrically connected to the meter by means of the two main line wires and an additional small wire operating the tripping magnet. These connections enter the instrument on one side, and those to the load are taken from two terminals on the other side. The arrangement will be followed from Fig. 229, which is a view of the separate prepayment device, with the cover and escapement mechanism removed. By means of a contact device on the registering train of the meter, the circuit of the tripping electro-magnet is closed each time one coin's worth of energy is passing through the meter. When the energy corresponding to the last coin has been consumed, the

switch in the main circuit is opened, together with the auxiliary magnet circuit.

The 'Wood' prepayment device, just explained, is used in an exactly similar manner by the General Electric Company of America, either in electrical or mechanical combination with their Thomson and high-torque induction watt-hour meters.

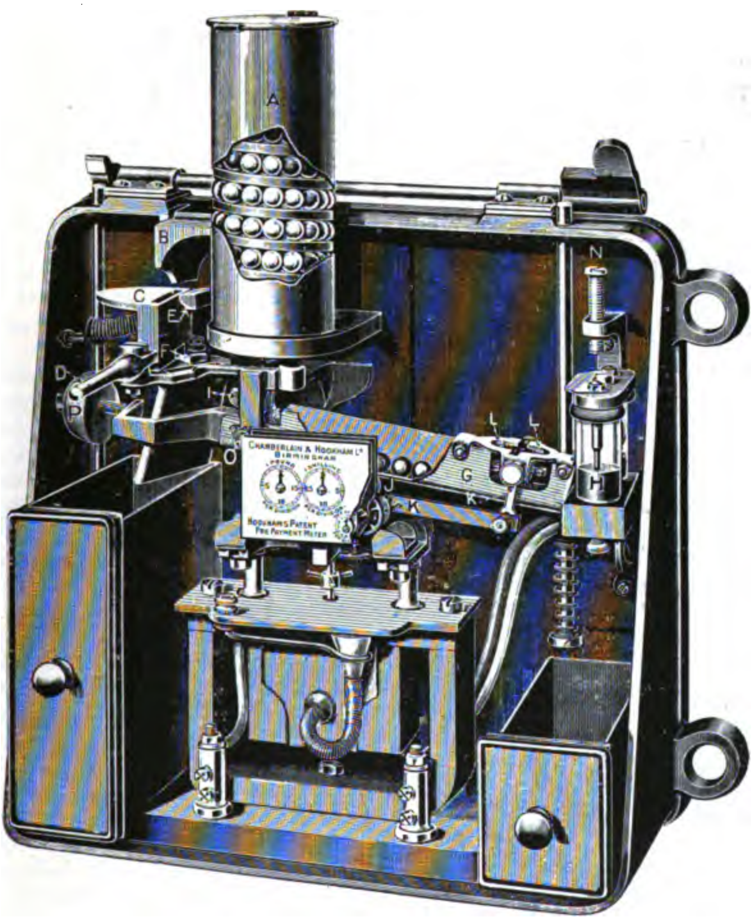

FIG. 230.

The Hookham Prepayment Meter.—The main features of the Hookham prepayment meter, as arranged for continuous current, are shown in Fig. 230. The method of operation is to employ the coin to release a corresponding check from a reservoir. This check causes a mercury switch to be closed. On the passage of a current, the rotation of the meter slowly removes the check when the predetermined amount of energy has been consumed and opens the circuit. No more current can then flow through the meter until a further prepayment has been made.

A is the check reservoir, shown partially broken to exhibit the checks, which, in the penny slot meter, consist of a number of small phosphor-bronze spheres contained in a spiral groove, from which they escape one at a time. In the shilling slotter, brass discs arranged in a tube are used instead of spheres. A coin is inserted in the slot at B and falls into the receptacle C, which is turned by moving the lever D to the left, when the coin, standing edgewise in C, first encounters and then lifts the catch E. The handle D can now be moved still further, and the coin will fall over the edge of the inclined plane F into the drawer on the left. At the same time, due to this forward motion of D, a small pusher under the reservoir A causes one check to drop into the beam G. It will be seen that, unless a coin has been inserted in the slot, the lever D can only be moved until the receptacle C comes into contact with E, when further motion is arrested and a check cannot be released. The small inclined plane F is to prevent the release of a check until a coin has been discharged into the till, and also to prevent the passage of more than one check for each coin. The disc or ball always drops into the beam slightly earlier than the coin gravitates into the drawer, so as to ensure the release of a check for each coin, but the check is not released until the coin has passed over the edge of the inclined plane. The importance of the part played by the inclined plane in preventing several checks from being obtained for the same coin will be understood from the following consideration. If the inclined plane were absent, by very slowly moving the handle forward a check could be released from the reservoir without the coin sliding down the shoot into the drawer, as the coin is always discharged later than the check. The handle could then be returned to its normal position and moved forward again, when a second check would drop through, and so on.

The inclined plane, however, effectually prevents this, as the coin, owing to the supposed very slow motion of the handle, will be resting against the vertical surface of the inclined plane when the check falls, and the handle cannot be returned until the coin has passed into the coin till.

The beam is pivoted at O, and carries at its one extremity the plungers of a mercury switch, and at its other the counterweight P. The position of the counterweight is such that when empty the beam rises out of the mercury cups H, but is at once depressed by the weight of one check. The passage of the check into the beam, therefore, closes the main circuit through the mercury cups. The speed of the meter and the wheel train of the counter are so adjusted that one check is released from the beam each time the corresponding amount of energy has been delivered. As each check falls into the beam it passes over and tilts a small weighted lever I. This lever is so arranged that when the beam holds from 6 to 8 discs or 12 balls, more cannot issue from the receiver, and at the same time the insertion of more than this number of coins is prevented until, under the action of the meter, a check has passed from the beam into the drawer on the right-hand side of the instrument. The checks are released from the beam by means of an escapement worked by the counting train of the meter. In the illustration of the instrument (Fig. 230) the latest form of the escapement is not shown; it is separately given in Fig. 231. The release mechanism, as shown in Fig. 230, will be understood from the following. One of the wheels of the counting train carries a crank-pin, J, which, in rotating, rocks the connecting rod and lever K K backwards and forwards. This lever K has attached to it a horizontal bar with two small vertical screws L L, forming the escapement. The rocking motion raises and lowers first one screw and then the other,

which allows the checks to fall one at a time into the drawer. In the improved release mechanism (Fig. 231), the lever K terminates in an escapement V, which controls a star wheel S. The connecting rod and lever K K are oscillated by the counterbalanced crank arm J, which is rotated by the integrating train when current is flowing in the circuit. The star wheel S is driven by the weight of the checks M in the beam G, and one of its teeth is released by the escapement V each time the predetermined amount of energy has been consumed, so that the only extra work the meter has to perform consists in actuating the escapement. Simultaneously with the release of a tooth of the star wheel, a check drops from the beam.

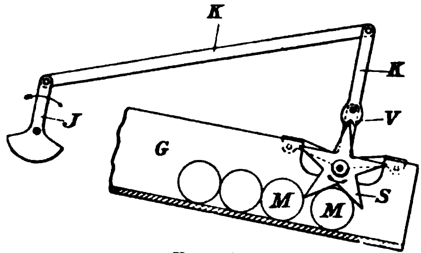

FIG. 231.

The coin and check drawers are secured by vertical spring bolts which are depressed by the horizontal bar on the top of the case. This bar also opens and closes the reservoir cover and a small hole in the case. The hole gives access to the screw N, which, in the lowered position, presses the end of the beam firmly down upon the mercury cups, effectually sealing them against loss of mercury in transit. On fixing the meter this screw must be raised to its fullest extent. The counter, a view of which is shown in Fig. 232, registers in the usual way the amount of energy consumed, and shows

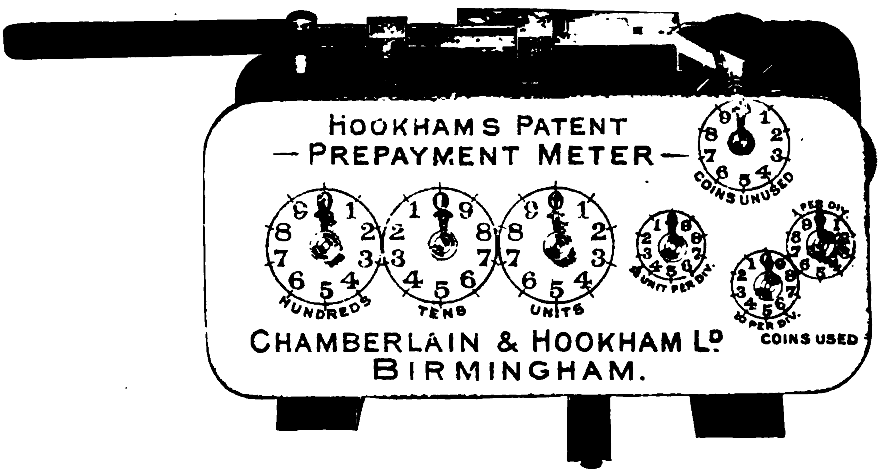

FIG. 232.

on the upper right-hand dial the coins still to the credit of the consumer. The two lower dials indicate the number of coins which should be found in the drawer of the meter.

The Mordey-Fricker Prepayment Meter is a modification of the Mordey-Fricker ampere-hour meter described on page 50, the winding up of the clock of the meter proper being performed on the insertion of a coin and turning the handle of the prepayment mechanism. The meter spindle is

extended through the box containing the mainspring, and terminates in a screw-thread with a nut, which operates the instrument switch and credit dial. When a coin is inserted in the slot it forms a key between the handle and a toothed wheel which engages with a pinion on the spring barrel shaft. To this spring barrel the mainspring is attached at its one end, its other end

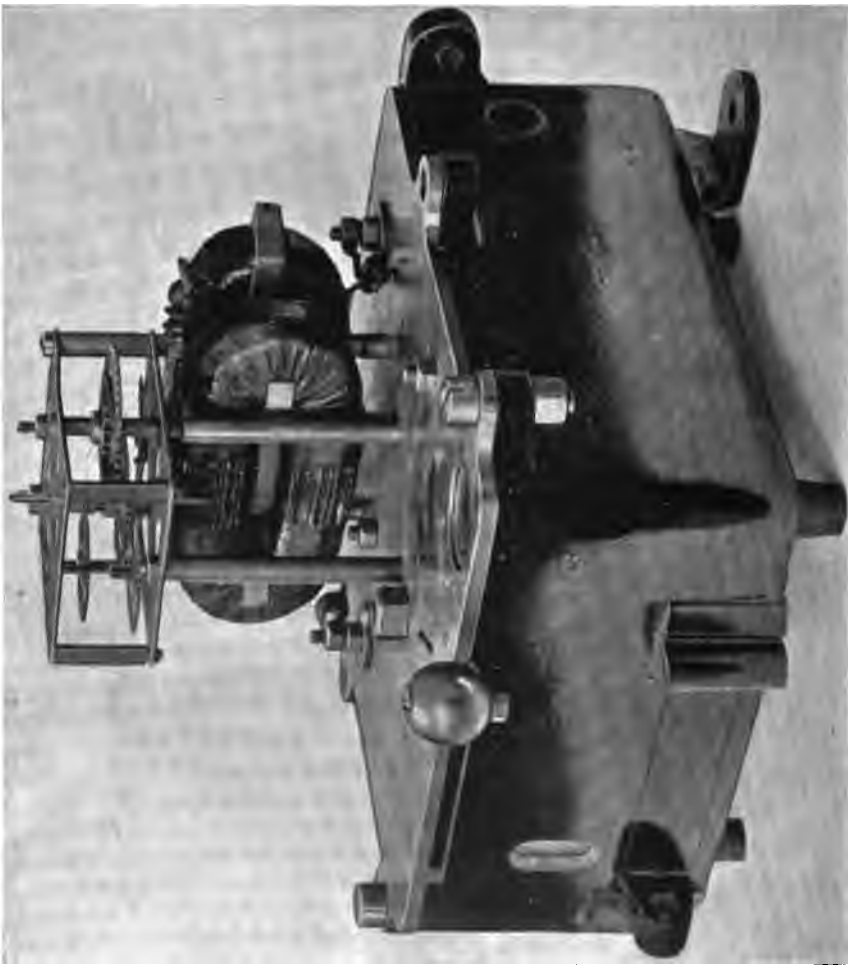

Fig. 233.

being fixed to the meter spindle. On turning the handle until the coin drops into the money box the spring is wound up a definite amount, and the nut is turned through one complete revolution and travels through the distance of one thread along the meter spindle, which remains stationary during this operation. The motion of the nut pushes forward a lever and closes the instrument switch, at the same time turning the hand of the credit dial to a

figure which indicates the amount prepaid. The same action of the handle also turns, through the toothed wheel on the shaft, a small counter, which registers the total number of coins inserted and acts as a check on the collector. The operation of inserting a coin and winding up the clock can be repeated until, in the particular instrument illustrated in Fig. 233, six coins have been prepaid. At each such insertion the mainspring is wound up to the same amount, the check counter is moved to the next higher figure, and also the credit index, and the nut travels up the meter spindle, pushing the lever still further out. When current is taken, the meter spindle revolves at a rate dependent upon the strength of the current, and in the same direction as that in which the nut was previously turned. The latter thus

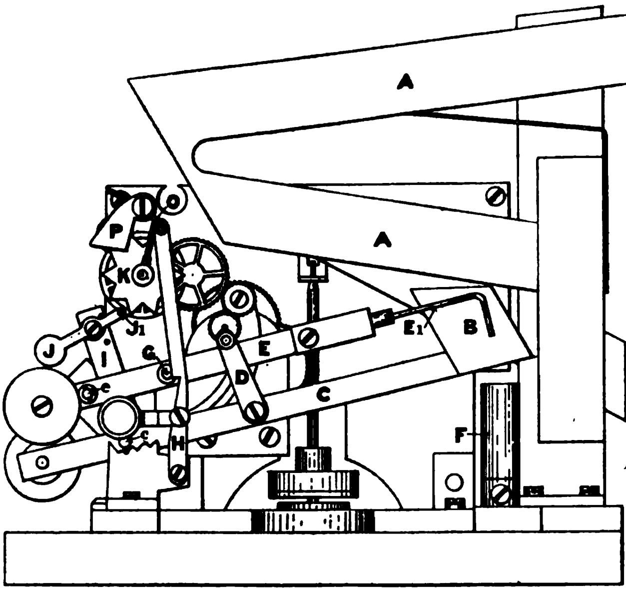

FIG. 234.

gradually travels back to its initial position, returning the index on the credit dial, which shows at every moment the amount still standing to the credit of the consumer, to the zero position, at which the switch is automatically opened. Current cannot now be taken unless further prepayment is made.

By means of the check counter and credit dial the meter proper registers accurately the units consumed at the pressure of supply.

The instrument can be constructed for different coins, and by a change wheel in the gearing can be adapted to supply at any price per unit.

The Reason Prepayment Meter.—The prepayment attachment used by the Reason Manufacturing Company, Ltd., Brighton, in their prepayment mercury motor meter, will be understood by reference to Figs. 234 and 235.

The coin is inserted through a slot in the meter case and slides down a shoot A into the coin receiver B. This receiver forms the one end of a counterweighted coin lever C, which is pivoted at *c*. When the coin

gravitates into B, the lever is tilted through a certain distance and the coin then drops into the money box. This movement of the coin lever actuates a mercury switch, a credit dial, and a check counter. As soon as the coin leaves the receiver B, the counterweight returns the lever C to its original position. The mercury switch consists of the mercury cups F and the contact bridges E_1, the latter attached to the one end of a contact lever E, pivoted at *e*, and furnished at its other end with a counterweight. When the mercury switch is open, the contact lever E rests against the arm D, carried by the lever C. The switch is closed on the coin lever C being depressed by the coin, when the contact lever E is drawn down by D, and the contacts made to dip into the mercury in the cups. The lever E is then locked in position by its pin G engaging with the locking arm H.

The star wheel K is moved forward one tooth for each depression of the lever C by means of the pin J_1 on the pawl J, attached to the arm I, which in turn is carried on the coin lever. This star wheel is fixed on the sleeve of one wheel L of a differential gear, of which the other wheel M gears with

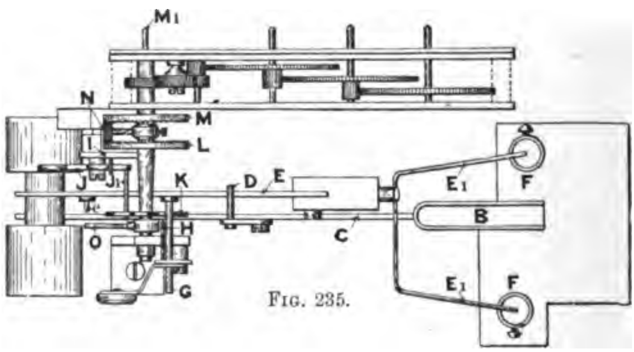

FIG. 235.

the integrating train of the meter. Both M and L rotate freely on the spindle M_1, to which the differential pinion N and the switching-off arm O are fixed. When the star wheel K is turned by the coin lever, the wheel L drives the pinion N and the pin O forward through a proportional distance, and the star wheel K is retained in position after each forward movement by means of the spring P.

On the passage of a current, after the insertion of the first coin closes the circuit, the meter train rotates through the differential wheel M the differential pinion N and the pin O in the reverse direction, at a rate proportional to the current and to the price per unit for which the meter has been adjusted. This condition obtains until the energy consumed corresponds to the amount prepaid, when the pin O forces back the stop-piece H. The contact lever is then released and springs back against the arm D of the coin lever, and the circuit is opened. A further prepayment must then be made before current can be taken. The spindle M_1 also carries an index, which shows on the credit dial the coins standing to the consumer's credit, and which is brought back to zero when the meter proper is working. The total number of coins paid into the meter is also registered on a small counter, which is moved each time the coin lever is depressed.

It will be noticed that the device operates directly on the insertion of a coin without the use of a handle. The attachment may be made for any

coins except small ones, such as a sixpenny-piece. The general construction of the prepayment meter, with the cover removed, is given in Fig. 236.

General Electric Company's Prepayment Meter.—In addition to the 'Wood' prepayment attachment, described on page 231, the General Electric Company, Schenectady, U.S.A., use their Thomson meter, somewhat modified, in combination with a separate prepayment device. The two instruments are mechanically independent of one another, but are electrically connected.

The meter differs from the standard type in the construction and arrange-

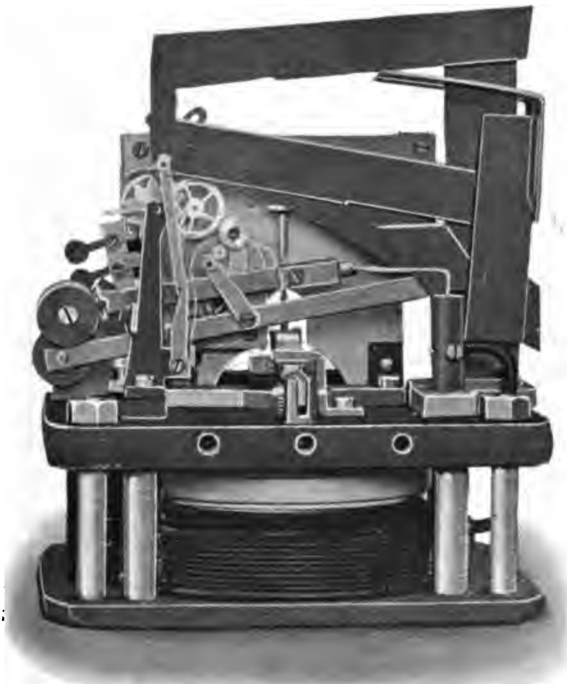

FIG. 236.

ment of the registering train and a few minor details, so that an ordinary Thomson meter without the special register cannot be used for the prepayment system. The register of the meter is fitted with a commutator which momentarily closes the circuit of an electro-magnet in the prepayment mechanism. Fig. 237 is a diagrammatic representation of the connections of a two-wire watt-hour meter with the prepayment device, showing the commutator, the electro-magnet, and the double-pole circuit switch. In the prepayment instrument a registering wheel is used, which is very clearly shown in the interior view of the prepayment device given in Fig. 238. The insertion of a coin in the slot locks the spindle of the handle and the shaft carrying the switch and registering wheel, which is rotated forward against a spring through one notch. If the circuit be open when a coin is deposited,

the same motion of the handle closes the circuit switch. A portion of the registering wheel is visible through the glass window in the cover, and plain numerals on its face indicate the number of coins still remaining to the credit of the consumer. He is thus able to ascertain at any time how much energy he can obtain before having to insert more coins. When the first coin has been deposited and the handle moved, the main switch is closed and the numeral '1' comes into view. The insertion of a second coin, before the current purchased with the first one has been consumed, allows of a second motion of the registering wheel, and this will bring the figure '2' in front of the window.

Twenty coins can in this manner be deposited, after which the slot is auto-

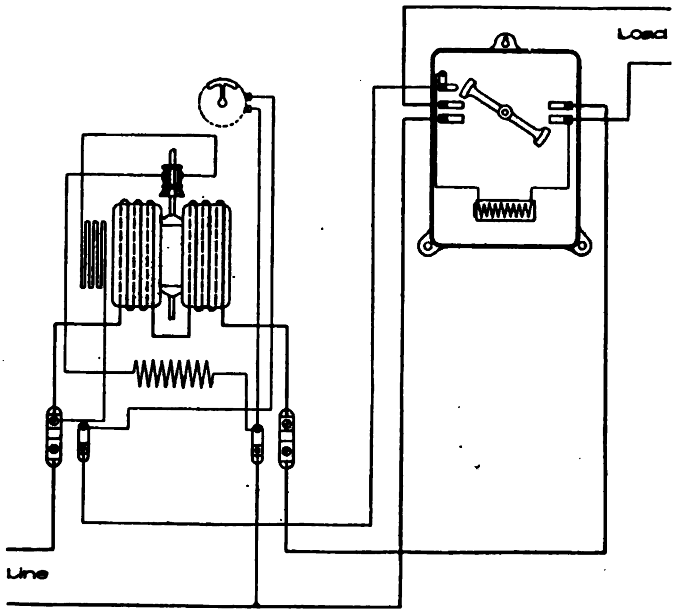

FIG. 237.

matically closed, as the handle cannot be turned back to its original position, and further prepayment cannot be made until the energy corresponding to the value of one or more coins has been consumed.

Whenever the energy value of one coin has passed through the meter, the commutator on the meter register momentarily closes the circuit of the electro-magnet. The armature of the latter is attracted forward and a catch is released so that the registering wheel unwinds by the amount of a single tooth, when motion is again arrested. When a further equal amount of energy has been taken, the operation is repeated. This process continues until all the energy for which prepayment has been made has been delivered, when the registering wheel moves back to the first notch and opens the switch. No more current can now pass until another coin has been deposited.

As already pointed out, the prepayment mechanism only shows the number of coins which stand to the credit of the depositor, but the dial of the meter

always indicates the amount of energy delivered, and thus serves to check the number of coins in the coin receptacle. This latter is made detachable and can be separately sealed, so that the collector only has to remove it and replace it with an empty one.

The prepayment device is manufactured in one standard size, designed for the deposit of dimes, which represent the most commonly used coin in America, so that prepayment can be made for $2.00 worth of electrical energy at one time. The selection of the commonest coin as the unit of the prepayment system is important, as it avoids inconvenience to a customer when a deposit is necessary.

The Prepayment Meter of the Compagnie pour la Fabrication des Compteurs, Paris. — A similar method is used by this company and by the Danubia Actiengesellschaft, Vienna. An illustration of the former company's prepayment meter is given in Fig. 239. The meter proper is electrically connected to a separate automatic instrument, and in the case illustrated the meter is their O'K. type. The coin is inserted in the slot at D, and the handle M turned from left to right as far as it will go, when it is brought back to its initial position. This action closes the circuit switch in the prepayment instrument, and a quantity of electrical energy can be taken corresponding to the value of the coin. When this amount of energy has been delivered, a contact controlled by the train of wheels of the meter counter completes the circuit of an electro-magnet in the automatic instrument; the electro-magnet becomes momentarily energised and by means of its armature opens the circuit switch. Current is thus cut off until a further prepayment has been made. Ten coins can be successively inserted in the manner described, when further prepayment is automatically prevented until an amount of energy corresponding to one coin has been consumed. It will be seen that the only modification introduced into the meter proper is in connection with the registering mechanism, the dials of which give direct, in the usual manner, the units delivered.

Fig. 238.

A small dial, visible through a window behind the handle M of the prepayment mechanism, shows the number of coins standing to the credit of the consumer. The hand on this dial is gradually brought back to zero during the passage of a current, and reaches the zero position when the instrument switch is opened.

The Watson Prepayment Meter, manufactured by the Rochdale Electric

Company, Limited, Rochdale, differs in many details from the prepayment meters which have, so far, been described. These, it will be remembered, consist of two distinct parts, namely, the prepayment mechanism and an

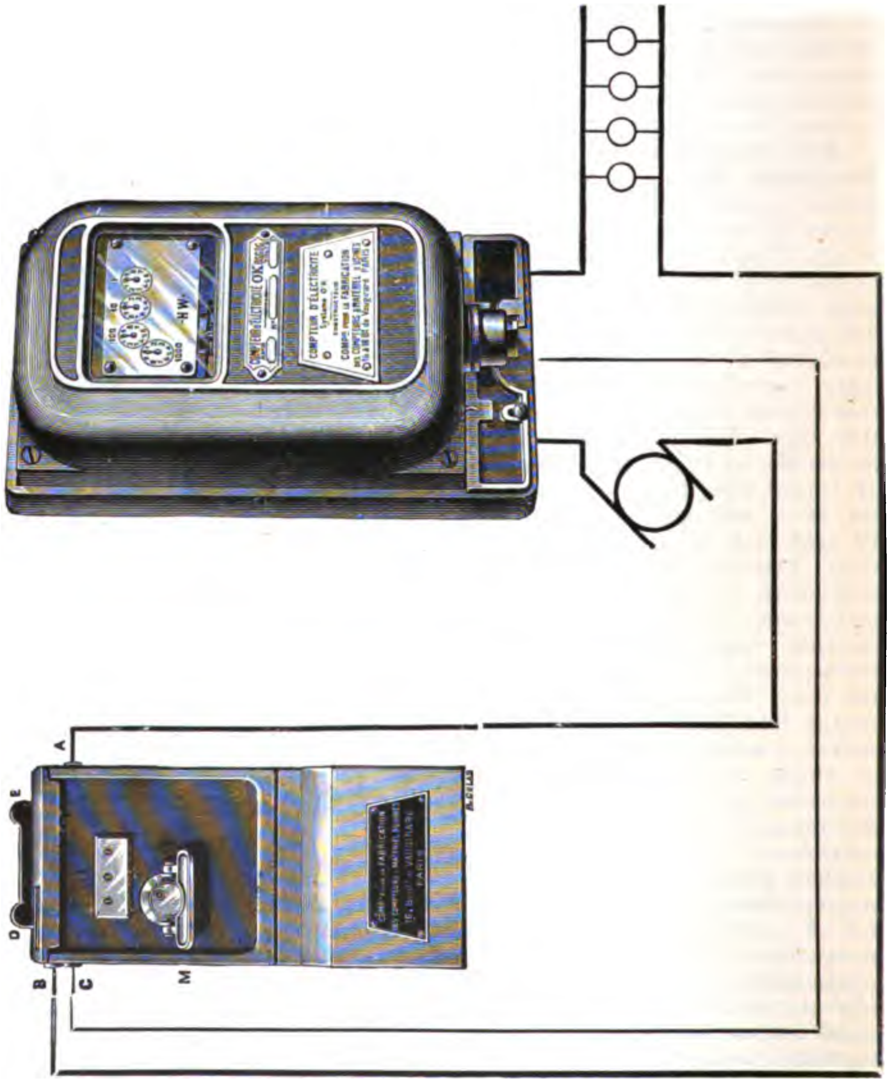

Fig. 239.

electricity meter proper, the latter being suitable for either continuous or alternating currents, or both. The two parts are either mechanically combined and mounted in one case, or they are simply electrically connected and are then used as two instruments. The meter itself does not differ in its main

features from the type to which it belongs, the only modification generally introduced into it being in connection with the registering train.

In this case, however, the meter is a specially designed prepayment meter for use in supplying current to small consumers, and the electrical portion by itself cannot function as an electricity meter.

Fig. 240 is a view of the Watson slot meter, with the cover open. It comprises two trains of wheels, one of which is the registering train and the other oscillates a special zigzag lever. The motion of this lever sets free and regulates the escapement of the recording train, and is, in turn, controlled by an electrical governor, which limits the extent of its swing according to the strength of the current flowing. The governor consists of a finger attached to the soft iron armature of a solenoid, which is connected in series with the main circuit through the switch in the meter. The more lamps there are in circuit, the more strongly will the armature of the governor be drawn into the solenoid, and the greater will be the amplitude of the swing of the oscillating lever, and, in consequence, the more quickly will the registering train be driven.

FIG. 240.

The parts of the instrument are shown diagrammatically in Fig. 241. When a coin is inserted in the slot and has been turned round until it drops through, it comes into contact with a bell-crank lever A and removes the toe of the lever from its position in contact with a cam on the cam shaft B, which is now free to be turned. The knob C on the shaft is then turned through one complete revolution in the direction of the hands of a clock, as indicated by the arrow on it, when it is locked. This action closes the switch at D D, and brings an adjustable sector E, on the cam shaft, into contact with a disc F. This disc is turned round, and moves with it the pointer or indicator M, over the face dial W, to a numeral indicating the number of lamp-hours corresponding to one penny. At the same time the cam causes the bell-crank lever A to move forward, allowing the coin to drop into the till. In the diagram, a penny is clearly shown in the position ready to fall into the coin receptacle.

The meter will now work on the passage of a current. This operation may be repeated until the maximum number of lamp-hours on the dial is indicated. The maximum so reached cannot be exceeded, as, on any further attempt to turn the knob, the sector E will revolve in an annular space on the disc F at this point. In this manner the mechanism is safeguarded against injury and cannot be locked. H is the zigzag lever which frees the escapement G of the recording train through the escapement lever L. The lower end of H is notched, and near its upper end it has a series of zigzag grooves, corresponding in number to these notches. In the zigzag grooves a small pin K works, and, when the oscillating lever H is swinging, rocks the escapement lever L to and fro, to which it is connected. The escapement lever L engages with the

escapement wheel G of the recording train, and thus works the pointer M back to zero.

It is so arranged that one tooth of the escapement wheel is released for each zigzag.

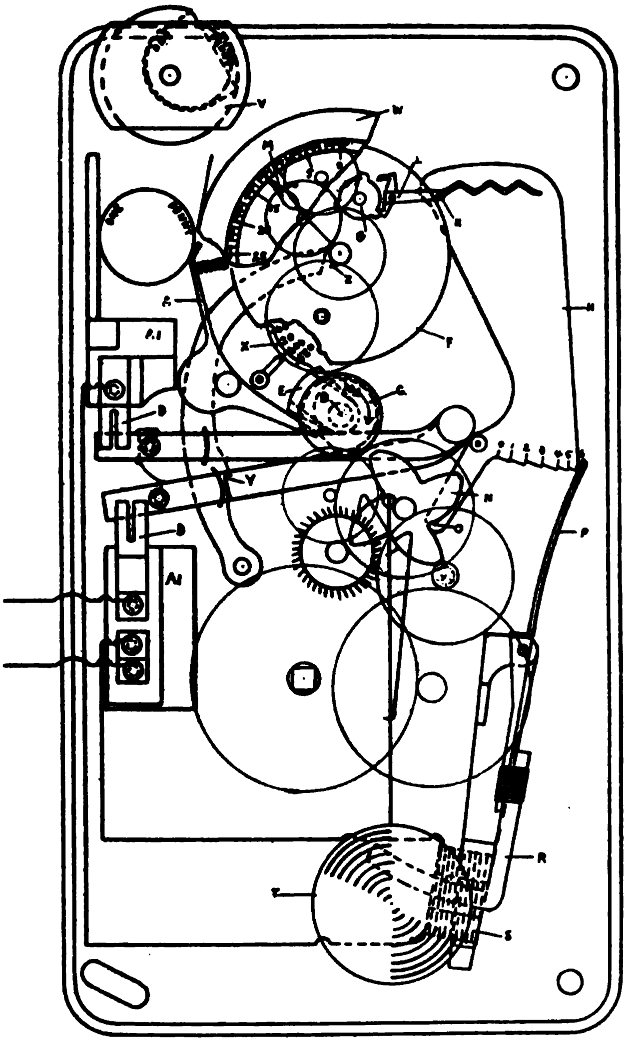

FIG. 241.

The oscillating motion of H is obtained from the pendulum clock through the pin O, which engages with the cam N, mounted on a continuously revolving shaft. P is the governing lever attached to the armature R of the solenoid S. The steps from 0 to 6, at the bottom of the lever H, are so arranged that, when the tip of this governor engages with these steps, the escapement G is

free to move 1, 2, 3, up to 6 teeth, according to the position of the governor tip. This position depends upon the extent of the attraction of the armature R into the coil S, and, therefore, on the number of lamps in circuit.

When no current is flowing, the lever H is held out of reach of the cam N by the governing lever, and consequently does not move. Although the pendulum bob T continues to swing, no movement of the pointer M on the face dial W can take place.

During the operation of the meter the indicator is gradually being brought back to the zero position ; the moment it returns to zero, the circuit switch D is opened by the pin Z on the dial hand shaft, coming into contact with and forcing away the lever with the catch Y. No current can then be taken until further prepayment is made.

The face dial W, in the front of the meter, reads in lamp-hours, and indicates at every movement the number of lamp-hours which stand to the credit of the consumer. A check dial X is fixed on the main wheel of the recording train, and can be read through a hole in the front dial. It shows the number of lamp-hours consumed, and forms a check on the collector.

The coins found in the till multiplied by the lamp-hours per coin should equal the sum of the check and face dials, less the previous readings. In the event of the rate of charge per unit being altered, the number of lamp-hours per coin can be increased or decreased without displacing the meter from its position by increasing or decreasing the arc of contact of the adjustable sector E with the disc F.

The meter is calibrated by cutting the notches in the oscillating lever to correspond with the movement of the armature, which is centred in jewels.

At V will be seen the coin trap used, which effectually prevents the insertion of a suspended coin, wire, or a coin of abnormal proportions.

CHAPTER XII

TARIFF AND HOUR METERS.

Definition of Maximum Demand Indicator—Aron Maximum Demand Indicator—Atkinson-Schattner Maximum Demand Indicator — Fricker Maximum Demand Indicator—Maximum Demand Indicators of the Reason Mfg. Co., Brighton—General Description of Two-rate Meters—Deutsch-Russische Tariff Meters—Electrical Company's Two-rate Meters—Hookham Two-rate Meter—Siemens-Schuckert Double-tariff Meters—Aron Two-rate Meter—Two-rate Meters of the Compagnie pour la Fabrication des Compteurs, Paris—Double-tariff Instrument of the Luxsche Industriewerke—Hour Meters.

Definition of Maximum Demand Indicator.—In the present chapter, descriptions are included of some representative types of maximum demand indicators, double-tariff or two-rate meters and hour meters. The principles involved have already been discussed in Chapter X.

A maximum demand indicator is an instrument which registers the maximum current taken in an installation during a given period, and its scale shows, at the particular supply pressure, the number of units, corresponding to each maximum current so taken, that must be consumed during stated periods before a reduction is made in the price per unit. Maximum demand indicators are based on either the thermal or electro-magnetic effect of a current, and on the principle of intermittent integration. A demand instrument should only register the excess current when that current has been flowing for an interval exceeding the time lag of the instrument, which should be large and depend on the nature of the installation, that is, whether the indicator is connected to a purely lighting circuit or is operating on a load comprised of motors. Increments of current of short duration, as, for instance, switching on a few extra lamps for a few minutes, or temporary short-circuits, should not cause an increase in its registration.

If a steady current of A amperes be flowing in a circuit, the indicator will, of course, show A amperes, but if the current be increased to A + B amperes, and the increment, B amperes, only lasts a few minutes, then the indicator should not record more than the original current.

The Aron Maximum Demand Indicator.—By means of an ingenious and slight addition to the ordinary Aron meter, it is made to function both as a meter proper and as a maximum demand indicator. The same instrument will, therefore, not only register the units consumed in the usual manner, but will also give the maximum energy taken during a given time interval, and, consequently, the units that must be consumed during that interval before a rebate is made.

It will be remembered that the differential clock of the Aron meter is driven by means of a small motor, and that the oscillation differences of the two pendulums, produced when current is taken by the installation, are

integrated by the clock and given on the dial, the indications of which represent the energy consumed over any desired period. The power of the driving motor thus available is utilised to drive an additional train of wheels, by means of which a pointer is intermittently brought into gear with, and is, in turn, actuated by, the integrating train of the meter. The position of the maximum demand pointer on its dial is determined by the angle through which the first wheel of the counter has turned in a given time. Fig. 242 is a front view of the instrument, showing very clearly the maximum demand dial above the springing integrating counter. The maximum demand pointer is loosely mounted on its spindle, which, at the back of the dial, carries a toothed wheel. This wheel engages with the pointer by means of a pin attached to the latter, and is driven from the integrating train.

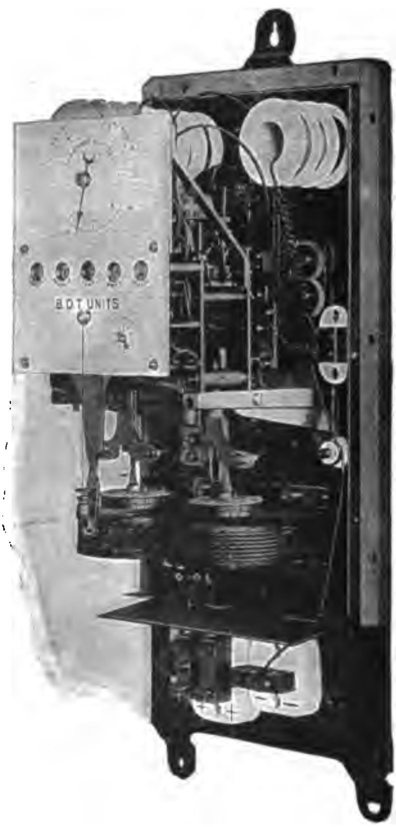

FIG. 242.

The commutator axle of the meter drives through a toothed wheel an intermediate set of wheels, which actuate a pivoted lever, on which is mounted another small wheel, which forms the connecting link between the integrating train of the meter and the toothed wheel on the pointer spindle. This small connecting wheel is thrown into gear once every twenty minutes, but only remains in gear for half this interval. This period of twenty minutes can, however, be increased or decreased to any extent. The integrating train and the demand indicator are thus in gear during a definite time, and when the former is actuated, on the passage of a current in the main coils of the meter, the pointer on the maximum demand dial will be moved during this time at a rate dependent on the energy consumed. The position at which it ultimately arrives at the end of the period will be a measure of the maximum demand in units.

At the termination of this time the small connecting wheel above referred to is thrown out of gear. The pointer will now remain stationary, and a light hairspring, which is wound up on the driven wheel of the pointer axle as this wheel rotates, unwinds and quickly returns the wheel to its zero position, leaving the pointer behind. This wheel will be again driven as already explained. Before, however, it can move the demand pointer, it must travel round until it again engages with the pin of the same. This will only happen provided that the demand during the new period is in excess of the former one, when the pointer will move further round and indicate the new maximum. To re-set the demand dial, it is only necessary to turn the pointer

back to the zero position. In addition to the advantage of one instrument giving both the actual units consumed and the maximum demand, however small, the law of the meter being a straight line law, the demand mechanism, as it is driven by the meter, is strictly proportional throughout the range of the latter.

The Atkinson-Schattner Maximum Demand Indicator, the latest type of which is illustrated in Fig. 243, works on the electro-magnetic principle. It is simply a gravity control ammeter of the solenoid type with a soft iron core, and is provided with a special time-lag registering device. The solenoid is bent into an arc of a circle and is fixed in the case on the left-hand side. The circular core is composed of thin iron sheets, increasing in number by gradual steps within the solenoid.

These iron plates are insulated from one another with a coating of varnish to prevent eddy current loss when used on an alternating current circuit, and

FIG. 243.

the section of the armature core is graduated to obtain as uniform a pull as possible. The core is carried on the lower arm of a light aluminium frame, pivoted at the centre, and shaped in the form of a sector above the horizontal axis, round which it can swing. The top portion of the frame supports the registering device. This consists of an hermetically sealed glass tube affixed to an aluminium scale. The form of the tube is readily seen in the illustration; the tube itself is filled with a viscous fluid, and contains a number of steel balls in the circular portion. The curved part of the scale is graduated to read in amperes, and the current passing is indicated at any moment by the division of the scale below the pointer fixed in the top of the case. The scale has marked on it three vertical columns of figures, in the second of which the figures denote the amperes, corresponding to the number of balls given in the first column, which have passed round the bend of the tube into the radial limb, and the third column gives the units which have to be consumed during the quarter, at the supply voltage and maximum current, before any rebate is made.

The action of the instrument is readily followed. On the passage of a current through the solenoid the armature is attracted into it, and the whole frame is tilted round the horizontal pivot. The highest part of the circular portion of the tube is moved downwards to the right, and any ball beyond this point slowly slides down the tube until it passes the bend, and collects in the radial leg. The speed of travel of the ball is limited by the viscosity of the liquid (oil or glycerine) used. The number of balls in the lower limb depends upon the angular deflection of the whole frame, and, consequently, upon the current in the main circuit.

The duration of the current must, of course, be sufficiently long to enable the ball or balls to slide past the bend. Temporary short-circuits and vibration will not affect the instrument, and, due to its sluggishness of action, it will not register increases of current lasting only for a short interval of time.

To prevent loss of time in re-setting the tube, a duplicate scale, with a second tube fitted to it, is provided. When the reading has been taken and the indicator is to be re-set, the tube is detached from the frame by means of its scale, and is replaced by the second set. The one previously in use is then hung up on the pivots in the meter cover in the manner shown (Fig. 243),

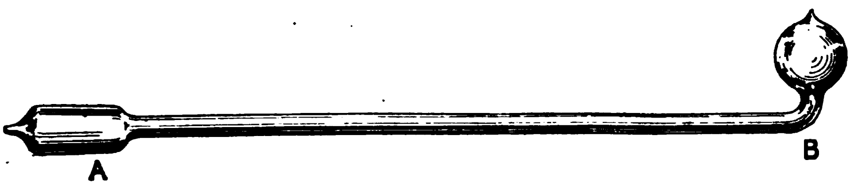

FIG. 244.

so that the balls return to the starting position ready for use. The scale is fixed to the aluminium frame by a hook at the top and a slotted pin at the bottom, to which it is locked by a small lever.

The Fricker Maximum Demand Indicator depends on the thermal effect of a current. The registration of the maximum demand is effected by means of a simple differential air thermometer, illustrated separately in Fig. 244. It consists of a tube of uniform bore, terminating in two hermetically sealed bulbs, of which the horizontal one A is cylindrical, and is the bulb to which heat is applied, and the other B is vertical and spherical in shape. At the end B the bore of the tube is closed by means of a globule of mercury, which acts as a valve; and to keep the surface of the mercury clean, hydrogen is used as the thermometric substance.

When a difference of temperature is established between the two bulbs, produced by a current flowing in the heating coil with which the bulb A is surrounded in the instrument, the enclosed hydrogen gas expands and escapes past the mercury valve into the vertical bulb B. After cooling has taken place, the gas contracts and draws the mercury thread along the tube from B towards A by an amount corresponding to the exact transference of gas from the heated bulb during the passage of the current. When the instrument is cold, *i.e.* no difference in temperature exists between the two bulbs, either on the discontinuance of the current, or when the tube has been removed from the instrument and cooled, the ultimate position to which the mercury

then travels in the bore is an exact measure of the maximum current taken, as shown on the scale attached to the tube.

A standard 10-ampere instrument is shown in Fig. 245, with the case open. The thermometer proper is mounted in a cast-iron longitudinal box, with the cylindrical bulb embraced by the heating coil, which is attached by flexible copper strips to the two terminals of the instrument, which must be fixed in a horizontal position. A small spring plunger with an insulating wedge serves, on opening the cover, to press these two copper strips slightly apart, to facilitate the removal of the thermometer for reading and re-setting the same. The action of closing the lid releases the plunger and causes the heating coil to firmly embrace and hold the cylindrical bulb of the tube. The plunger at the same time becomes clamped, and cannot be moved unless the case is opened. A small cooling chamber is fitted to one end of the box, and consists of a cylindrical vessel surrounded with a water-jacket, its function being to rapidly cool the thermometer when a reading is required. The bulb is placed in the cylinder, and after a minute the cooling of the thermometer is complete, when the mercury index remains stationary in the tube at a point corresponding to the maximum current taken. The operation of re-setting the

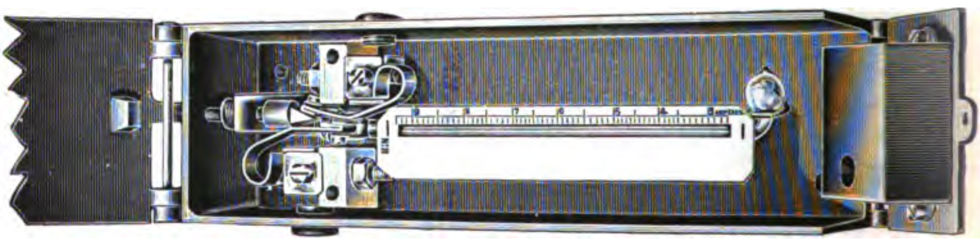

FIG. 245.

tube is very quickly performed. It is held in a vertical position, with the cylindrical bulb pointing upwards, and, on slightly tapping the tube, the mercury index will descend into the spherical bulb, and the valve will close the bore of the tube when it has been replaced in its horizontal position in the case. The instrument is then again ready for further use.

The consumer can read the maximum demand recorded at any time when the instrument is cold before switching on current, and can also easily ascertain the state of his present demand, *i.e.* whether he is within his previous maximum, by examining the tube through the window on the cover. If the mercury index be visible at all, the current flowing will be below this maximum; if, however, it be not visible in any part of the tube, then the previous demand has been reached, and possibly exceeded.

It follows, naturally, from the thermal sluggishness of the principle involved, that increases in the current strength of short duration will not produce abnormal registrations, as a current slightly in excess of a former one requires the full time to heat up the instrument. The time lag of the indicator can also be suitably increased, by increasing its capacity for heat, to apply it to the registration of the maximum currents taken with motor loads.

The Reason Company's Maximum Demand Indicators.—The maximum demand indicator, invented by Mr Arthur Wright, and made by the Reason

Manufacturing Co., Ltd., Brighton, is in principle a differential recording thermometer which registers the thermal effect of a current.

A view of the demand indicator, with the case removed, is given in Fig. 246, and is the standard type for capacities of $2\frac{1}{2}$ to 35 amperes. It consists of two hermetically sealed bulbs, of approximately the same size, united together by a U-tube, filled with a solution of strong sulphuric acid. Attached to the right-hand limb of the U-tube is a third tube, to which the scales are fixed. The liquid employed as the thermometric substance is chosen on account of its hygroscopic character, in order to keep the air in the bulbs free from aqueous vapour. The left-hand bulb is wound with a heating coil, which is traversed by the current taken by the installation. The heat so generated by the current in the coil gradually causes the air to expand and to depress the liquid column in the left-hand limb of the U-tube, so that it rises in the other limb and slowly overflows into the reading tube. The height to which the liquid finally rises in this tube indicates the maximum value of the current which has passed through the coil, and is independent of the nature of the current, so that the instrument works equally well on an alternating or direct current circuit. The tubes are very carefully annealed, to free the parts from internal stress and eliminate the possibility of secular charges. They are, in addition, constructed with a number of traps in each limb, as illustrated in Fig. 247, which represents one of the latest makes of tube. C and D are the two air bulbs, the middle tube is the reading tube in which the

FIG. 246.

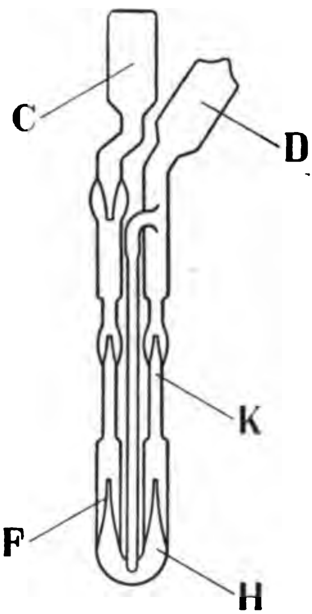

FIG. 247.

overflow collects, and the traps are shown at F, H, and K. The object of these traps is to prevent any transference of air from one bulb to the other during transit, or when the instrument is re-set while hot, and during the passage of a current. The tubes are carried on a board, which can be tilted about the hinged terminals, so as to allow the liquid to flow completely out of the reading tube into the right-hand bulb when the instrument is to be re-set to zero.

The two scales provided with the instrument indicate on the one the maximum current used in amperes, and on the other the units which have to be consumed in a given period before the reduced charge is made; these latter figures are set opposite the corresponding number of amperes. In those cases in which the duration of the high tariff does not remain constant during the year, as when the high rate is charged for a greater number of hours per month in the winter than in the summer, the instrument has a separate winter and summer scale of units, either of which is used at the proper season.

FIG. 248.

The scale of the instrument is long, and open in the working range between full load and one-fifth load. The calibration does not extend below this point, as the scale contracts, with a corresponding diminution of sensitiveness, when this value has been reached.

The error due to temperature variations of the surrounding air is almost negligible, except below one-fifth load and under abnormal conditions, as both bulbs are subjected in the same degree to these atmospheric changes; moreover, the measurements of the instrument depend only on the difference in temperature between the two bulbs.

The natural sluggishness of the instrument, which depends on the specific heat of the coil, the glass bulb, and the enclosed air, is increased by placing a cylinder of iron in a pocket in the heating bulb, to adapt the indicator for use on arc-lamp and motor loads. The extra capacity for heat of the iron causes the indicator to record as slowly as may be required.

From the thermal principle involved in the instrument, it follows that when the passage of a current has been stopped, the instrument gets quite cold, and a subsequent current requires the full time to heat the parts and to produce a steady temperature. The danger is then eliminated of a current a little higher than a previous one, but of short duration, causing the abnormal registration.

For heavy continuous-current work, the indicator is supplied with a shunt, as illustrated in Fig. 248.

For measuring the maximum demand of a three-wire installation, a special arrangement, due to Mr J. R. Dick, is used. The instrument is then fitted with two equal resistances of very low value, to the common junction of which

is connected the neutral wire of the system, and the heating coil of the indicator is joined across the ends of the two resistances in series, as shown diagrammatically in Fig. 249.

It follows, very simply, that the current in the indicator will always be proportional to the sum of the currents in the outer mains.

Referring to the diagram (Fig. 249), C_1 and C_2 denote respectively the currents in the outer conductors, and A is the current in the heating coil of

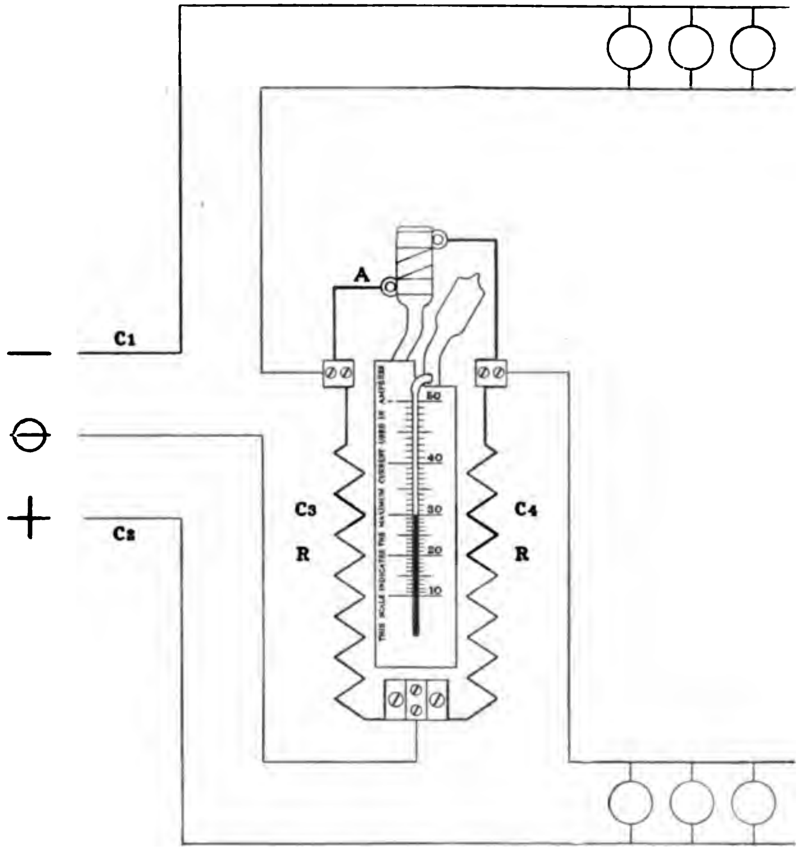

FIG. 249.

the indicator; C_3 and C_4 are respectively the currents in the two equal resistances R R, and r is the resistance of the indicator strip.

Then $\quad Ar = C_3R + C_4R.$

And $\quad C_1 = C_3 + A.$

$$C_2 = C_4 + A.$$

$$\therefore \quad Ar = R(C_1 + C_2 - 2A).$$

i.e. $$A = \frac{R}{r + 2R}(C_1 + C_2).$$

That is, the current in the indicator is always proportional to the sum of the positive and negative currents, and one instrument can be used, with gain both in accuracy and economy.

The Reason Manufacturing Company have recently introduced two new types of demand indicators, one based on the electro-magnetic principle, and the other devised by Mr C. H. Merz, for supply-in-bulk schemes, and based on the principle of intermittent integration. The latter apparatus is an additional attachment to an ordinary ampere-hour or watt-hour motor meter, and consists of a pointer driven by the meter train, a maximum demand dial, and a clock which periodically re-sets the driving mechanism to zero. The first wheel of this driving mechanism is in mesh with the ordinary meter train, and rotates a spindle by means of a ratio wheel through a given angle in the period which elapses between the moments when the mechanism is re-set to zero. The ratio wheel is such that it nearly gives a complete revolution of the demand pointer, with the full load current flowing for one hour. The pointer is held in its maximum position by a small pawl, which prevents its being returned to the zero position by the automatic re-setting of the mechanism. At the end of each month the meter reader returns the pointer to its zero stop after releasing the pawl. On a fluctuating load the dial records the maximum consumption per hour during the time the meter is in circuit, and, whatever the instantaneous load, only the maximum averaged over one hour is registered.

FIG. 250.

The electro-magnetic demand indicator made by this company is illustrated in Fig. 250. It consists of a solenoid, through which the main current passes, and into which a plunger is attracted. A glass vessel containing a liquid forms the registering part of the instrument, and is tilted by the motion of the plunger. When this happens the liquid gradually flows through the constricted portion of the U-tube, and collects in the vertical reading tube to which the scales are affixed. By suitably altering the constricted part of the U-tube, the sluggishness of registration of the instrument can be varied, so that a full reading is not obtained until the current has been on for the desired interval.

The period for complete registration can, in fact, be adjusted between the limits of five minutes to three hours. A small quantity of liquid at the bottom of the reading tube serves to mark the zero reading when no current

is passing. The height of the liquid in the vessel is such that it overflows into the reading tube as soon as any tilting occurs. The tube is mounted on a pivoted zinc plate, and can be accurately set to zero by means of an adjusting counterweight.

Two springs are also provided to take up the shock of the sudden impetus imparted to the plunger on the passage of an excess current due to a short-circuit. Only a slight rise in the reading is observed on a short-circuit, except in the case of those instruments which have been made specially quick-reading for specific purposes.

To re-set the instrument to zero the tube carrier is turned counter-clockwise, after slacking the thumb screw immediately above the solenoid. When the tube has been thoroughly drained, the tube carrier is returned to its original position, and the screw is again tightened.

General Description of Two-rate Meters.—A double-tariff or two-rate meter is an ordinary meter, suitable for either direct or alternating currents, or both, and is fitted, in general, with two integrating mechanisms and a change-over device, by means of which the two integrating trains are alternately connected to and disconnected from the revolving armature spindle according to the particular tariff in vogue, the interchange between the spindle and either counter being electrically or mechanically effected by means of a time switch. The one integrating mechanism registers only during the high-rate and the other during the low-rate periods, so that the energy consumption at each rate is separately shown. A simple device is also used to indicate which counter is operating, and at which tariff. Two-rate meters, as will be seen from the above definition, may be divided into two classes, namely, electrically and mechanically operated two-rate meters. In the former case the meter and the time switch form two separate instruments, and are connected together by electrical means only, whereas in the latter case the time switch is mounted with the meter on the same base, and mechanically controls the change-over gear. In both types, however, the only modification introduced into the meter is in connection with the registering part.

The time switch, or, as it is variously termed, change-over clock, and double-tariff clock, is simply an ordinary clock, which at definite moments changes either electrical contacts, or alters the position of a mechanical change-over gear. In some cases the clock is fitted with an electrical, automatic self-winding arrangement.

Deutsch-Russische Tariff Meters.—A very interesting series of tariff meters is manufactured by the Deutsch-Russische Elektricitätszähler-Gesellschaft, Germany. For the ordinary double-tariff system, in which the low and high rate units are separately registered on two distinct counters, the combination used by this company is illustrated diagrammatically in Fig. 251, and consists of a time switch U, their ordinary meter Z, and a special set of test terminals P, mounted together on one common slab G of slate or marble. The test terminals P are usually supplied with the tariff meters, as they but very slightly add to the cost of the set of apparatus, and greatly facilitate testing *in situ*, and replacing the meter, if necessary, without interfering with the current taken by the particular installation. The meter proper, which in the illustration given is this company's special continuous current type, is fitted with two integrating mechanisms and a change-over gear, electrically operated and controlled by the time switch. An exactly similar arrangement is adopted with their alternating current meter. The pawl S, which is

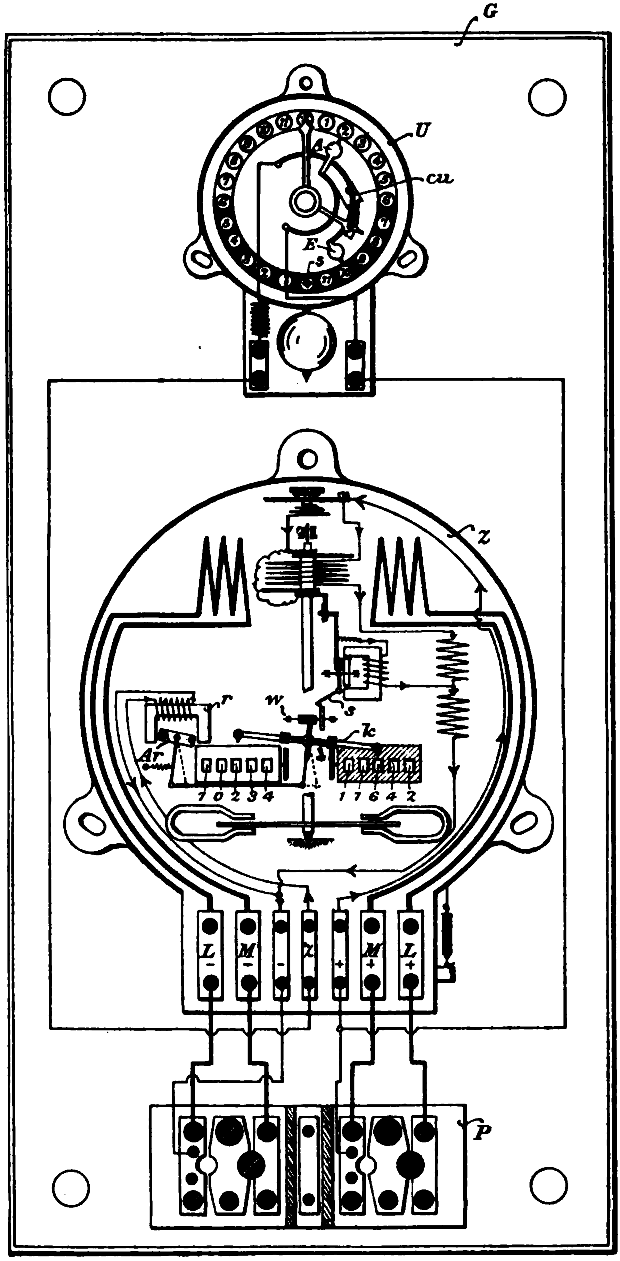

FIG. 251.

actuated by the relay of the meter proper, drives, at a speed proportional to the rate of rotation of the copper brake disc, both the spindle W of the counting mechanism and, through this spindle, the connecting gear K. This coupling lever is normally held by a spring in the position in which its right-hand pinion gears with the toothed wheel of the right-hand integrating train which registers the kilowatt-hours at the ordinary or low tariff, until the clock contact C U is closed. When this takes place at the commencement of the high-tariff period, the electro-magnet *r* becomes energised and attracts its armature A*r*, the motion of which causes the coupling gear K to become disengaged from the right-hand counter, which now stops, and to gear with the left-hand one, which is driven and indicates the units consumed during the tariff time set on the clock. When this tariff time terminates, the right-hand counter again becomes operative. A small coloured disc or indicator appears above the figures on the dial, as shown in the diagram, indicating at once which counter is registering and the tariff in vogue, as each dial is separately marked to indicate the tariff at which it registers. The time switch U is a hand-wound, forty-day pendulum clock, and is usually wound up once every three or four weeks by the meter inspector when he takes the meter readings. The clock is provided with a twenty-four-hour dial, which is divided into two equal white and black sections, to differentiate between the hours of day and night. The hour hand has attached to it the brush contacts to make and break the circuit of the electro-magnet *r* at the commencement and termination of the high-tariff period, which is set by means of the hands A and E.

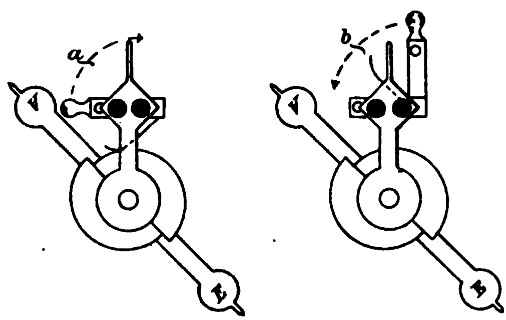

FIG 252.

The tariff time can be regulated between the limits of one and twelve hours, and the simplest method of setting it is to adjust the hands A and E to the time interval, during which the high rate obtains and the left-hand counter is coupled to the meter proper, and to turn the A-hand to the starting time, when the other hand travels round and the adjusted interval remains fixed.

The hour hand and the limit hands, A and E, are shown somewhat more in detail in Fig. 252, and before adjusting the tariff period the brush holder on the hour hand is turned through a right angle in the direction of the arrow *a*, so that, when the hands A and E are moved, the brushes are not damaged.

In contrast to the above, this company also manufacture a mechanically operated two-rate meter, which consists of the meter proper in mechanical connection with a time switch and a double-tariff integrating mechanism, the combination forming one complete instrument, as illustrated in Fig. 253. M is the minute hand, A and E are the two hour dials for the tariff time, P is the stationary hour hand, and P_1 and P_2 are the tariff hands, attached to two cams, loosely pivoted on the axles of the hour dials. The left-hand counter is for the low-tariff units, the right-hand counter gives the consump-

tion during the high-rate period, and a red indicator shows which counter is registering.

The operation of the time switch and change-over gear will be understood by reference to Fig. 254. The hour dials are driven from the pinion '3' on the axle of the minute hand through the pinion '5' and the toothed wheel '4,' and on the axles of these dials are the cams '8,' held by friction. The revolutions of the meter spindle are transferred to the toothed wheel '11' through a worm and a worm-gearing. The axle of this wheel is pivoted at

Fig. 253.

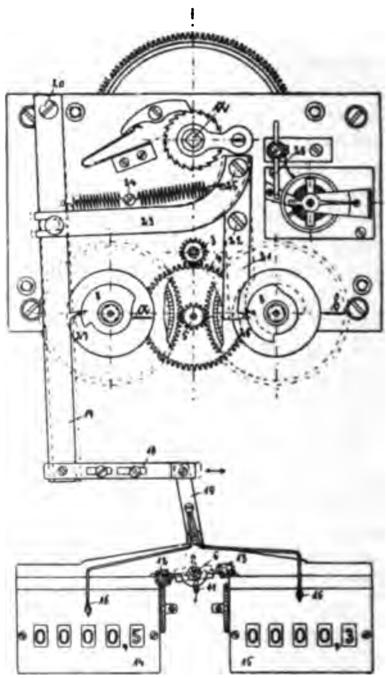

Fig. 254.

'6,' and carries at its ends the two pinions '12' and '13.' According to the position of the rocking bar '17,' and its arms '18' and '19,' either the pinion '12' is brought into gear with the driving wheel of the low-rate integrating train '14,' or the second pinion '13' is caused to mesh with the driving wheel of the high-rate counter '15.'

The lever '17' is pivoted at '20,' and is cross-connected through the bridge-piece '23' with the second lever '21,' pivoted at '22.' The toe '26' of the lever '21' is held pressed against the cam '8' of the right-hand dial E (Fig. 253) by means of a strong spring attached to the bridge-piece '25,' and, in a similar manner, the toe '27' of lever '17' is held against its cam, but by a weaker spring. When the toe '26' of the lever '21' falls below the

projection of the right-hand cam '8,' the bridge-piece '23' pushes the lever '17' away from its cam, and the low-rate counter '14' will be driven until the high-tariff period is reached. The toe of the lever '17' will then engage with its cam, and the high-rate counter '15' will become connected and will register.

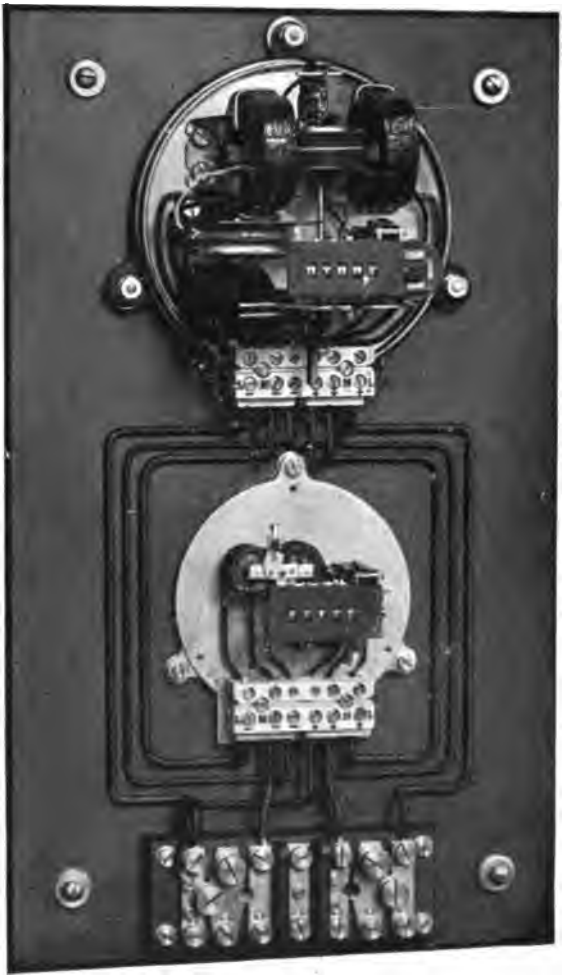

FIG. 255.

The clock is set to the time of day by turning the knob of the minute hand M (Fig. 253) until the correct hour on the hour dial A stands below the fixed pointer P, and the minute hand is either at or between the minute figures 15, 30, 45, 60. The commencement of the tariff time is set by rotating the knob on A clockwise until the hand P_1 points to the desired hour, and the termination of the tariff interval is set in the same manner by means of the hand P_2 on E. As soon as P_1 is vertically below the stationary hour hand P, the right-hand counter is coupled to the meter spindle and registers the units taken at the high tariff until the pointer P_2 comes into the vertical position, when the left-hand counter is again driven. The tariff hands must always be rotated clockwise, and, to prevent damage to the clock, the knobs, if turned in the contrary direction, slip without carrying the hands with them. The window in front of the dial is hinged, so that the clock may be wound and the hands set without the necessity of removing the meter cover.

When a uniform tariff is in vogue the clock can be entirely disconnected by moving to the right the lever '28' (Fig. 254), whereby the escapement of the clock is held by means of a light spring.

In connection with the system of charging, the principle of which is that

a certain number of units must be consumed before a rebate is made, and which has already been explained on page 212, this company use in addition to their meter a special step-tariff apparatus. Fig. 255 represents their D.T.S. type of tariff meter for this purpose. In this case the meter proper, which in the illustration given is their continuous current type, is not in any way modified, and registers in the ordinary manner the total units consumed. Below the meter is the special step-tariff apparatus, which registers only those units which are consumed above a certain load, about 30–40 per cent. of the full load capacity of the installation. The tariff is fixed according to the amount of this consumption. This system can be extended and several such step-tariff counting mechanisms used with the meter. In the case of two counting trains, the one step-tariff indicator will give the upper two-thirds of

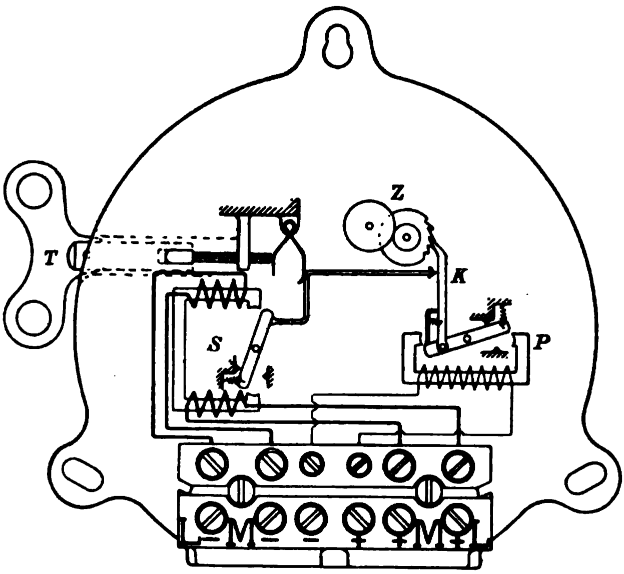

FIG. 256.

the load limit, while the top third of the load limit will be given on the other, and the meter proper will register the total units consumed.

A diagrammatic representation of the step-tariff apparatus is given in Fig. 256; it consists of a counting train Z, which is actuated by a pressure relay P exactly similar to that in the meter. These two relays are connected in series in the pressure circuit, so that when current flows round the meter relay, the one in the tariff instrument is also energised. The pawl K between the relay armature and the counter Z is made dependent upon a heavy current electro-magnet S, and it is only when the armature of the latter has been drawn in a certain amount, corresponding to a definite load, that the pawl K is free to move.

When this happens the motion of the pressure relay is transferred to the integrating train Z in exactly the same way as that in which the meter counter is actuated, and the kilowatt-hours consumed after the lower current limit, say 30 per cent. of the maximum, has been passed, are in this way

registered on the step-tariff apparatus. The heavy current electro-magnet S can be adjusted within wide limits by turning a screw on the left of the apparatus by means of a key T supplied with the instrument. Turning this key clockwise retards the action of the relay S, which will now require a stronger current to actuate it. In the tariff system introduced at Halle by A. Jung, an hour meter is used in connection with the watt-hour meter instead of the step-tariff instrument, and indicates the hours (not kilowatt-hours) during which the consumer uses current at loads equal to at least one-half of the maximum in regular daily use (see page 215).

The Electrical Company's Two-rate Meters.—The time switch of the

FIG. 257.

Electrical Company, Ltd., London, is illustrated in Fig. 257. It consists of a 32-day pendulum clock, with the whole of the switch gear arranged in front of the clock face. The large dial A of the clock proper is divided into two equal day and night portions, the latter being coloured black. The actual time is denoted by the minute hand M and the hour hand H, the latter completing one revolution in twenty-four hours.

Above the time dial is a second smaller one B which rotates with the hour hand, and the tariff period is set on this dial by means of a red hand R and a green hand G, affixed to two cams. These cams rotate with the dial B, and can be displaced relatively to it. In the course of the revolution of the hour hand, when the latter indicates on the time dial the hour at which the tariff change comes into effect, these cams break contact between the springs

F_1 and F_2 and establish contact between F_2 and F_3, or the reverse takes place. The cam to which the red pointer is attached is set to the commencement of the tariff time on the dial B, and the termination of this interval is fixed by the green hand on the second cam. After regulating the tariff period the clock is set to the time of day in the usual manner. It will be noticed that the clock has three spring contacts, F_1, F_2, and F_3.

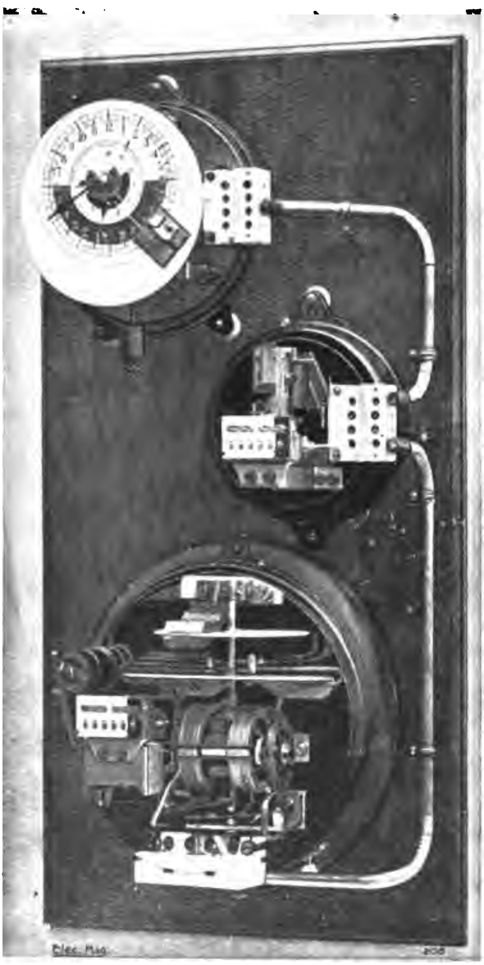

Fig. 258.

These three contacts are necessary when the time switch is used to electrically control a separate counting mechanism with this company's oscillating continuous current meter for a double-tariff system, in which the meter proper registers the total units consumed.

Fig. 258 is an illustration of the combination of apparatus used in this case. The meter itself is not modified in any way, and registers the total consumption. Between it and the time switch, mounted on the top of the slate or wood base, is the tariff apparatus, consisting simply of a second counting mechanism exactly similar to the relay counter, characteristic of this meter. The rebate instrument is connected in series with the time switch and in parallel with the meter counter. It only registers during the high-rate period set on the tariff clock. The advantage of this system is that the consumer can at any moment determine not only the whole amount of the energy he has taken, but also the energy taken at the high rate.

If this method be employed with any other type of continuous current meter, or on an alternating current supply circuit, two meters have then to be used, for which the one registers the total and the other the high-rate units.

In conformity with the general two-rate system, the Electrical Company also manufacture double-tariff meters for either continuous or alternating current, in which case each meter is fitted with two cyclometer counters and an electro-magnetic change-over gear. The same time switch is used, but it has two contacts instead of three, and electrically controls the operation of

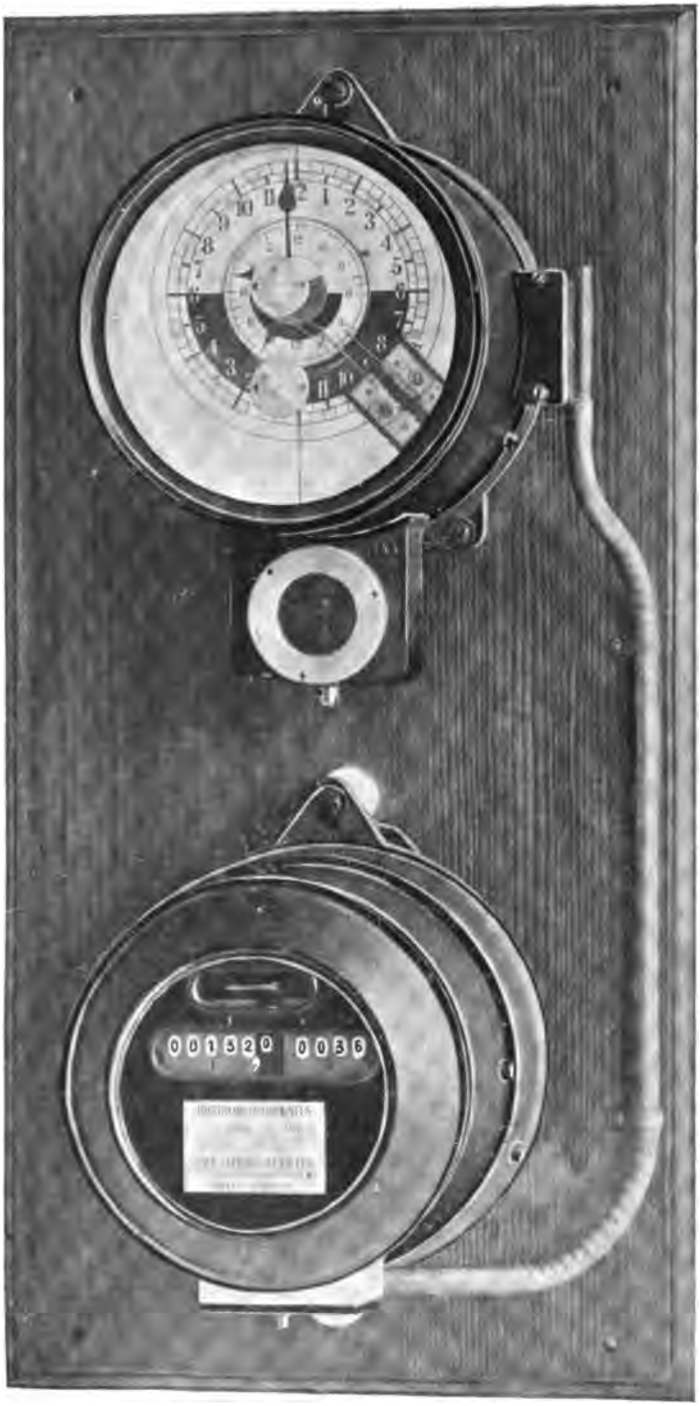

Fig. 259.

either counter through the relay and connecting gear, by which the one counter revolves during the high-rate time and the other when this time has been passed. The relay and time switch are connected in series across the supply circuit. An illustration of this company's double-tariff meter and time switch is also given in Fig. 259.

The General Electric Company's Two-rate Meter.—The two-rate meter of the General Electric Company, U.S.A., consists of their ordinary Thomson meter and a controlling clock in a separate case, the two being electrically connected, as illustrated in Fig. 260.

The clock, shown separately with the cover off in Fig. 261, is automatically wound by means of small dry batteries contained in the same case.

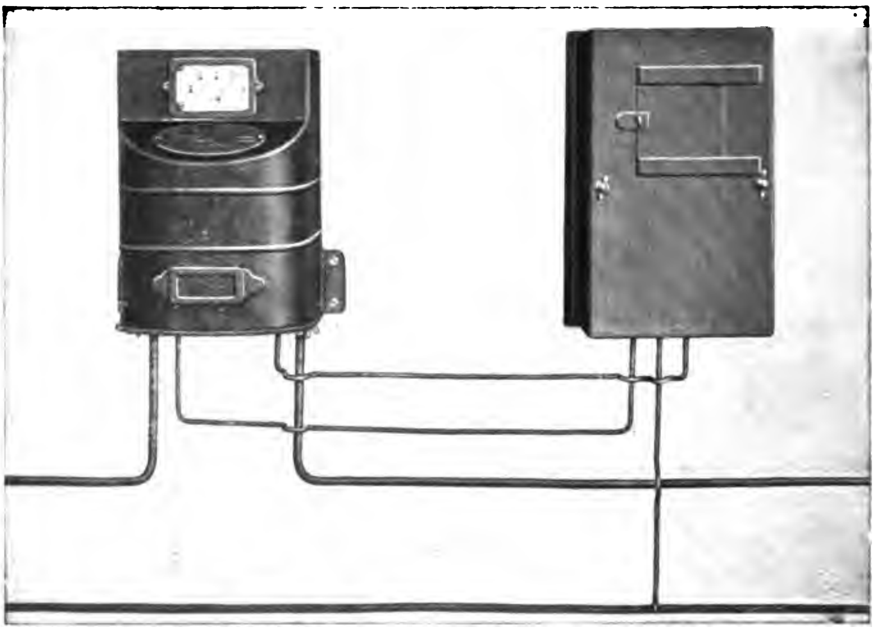

Fig. 260.

The clock has the hours from 1 to 12 for the day and night engraved on a metal plate. Above this plate are two pointers, by means of which the time for the change from each tariff to the other is set as in an alarm clock. The operation of the device is very simple. During the normal period of high tariff the armature of the meter rotates at full speed, corresponding, of course, to the main current flowing, and the full amount of the energy delivered is registered. At the hour when the predetermined low tariff comes into effect, the clock automatically inserts in the armature circuit an additional resistance mounted with it. This resistance is so proportioned that the moving element of the meter will now rotate more slowly than it ordinarily would, and at a speed reduced in the ratio of the low to the high tariff, *e.g.* if the ratio of the low tariff to the high tariff be $\frac{1}{2}$, then the speed will be one-half what it otherwise would be. The low speed will continue

until the end of the low-tariff period, when the clock automatically cuts out the resistance, and the meter then registers at its normal rate as before.

The meter has only one dial, and this dial always shows the number of units chargeable at the established, or high, tariff. It, therefore, does not record the true amount of the energy taken during both periods.

It is interesting to note here that the meter is an actual two-rate meter, rotating, as explained, at two different speeds, depending upon the particular tariff in vogue. It may be used on either direct or alternating current circuits, interchangeably, and whatever the frequency of the alternating current. It is, further, independent of whether the circuits are shut down for a portion of the time or not. The rotation of the meter can be checked by observing the revolutions of the brake disc, visible through the window provided for this purpose in the meter cover, so that the change of speed from one rate to the other may be verified.

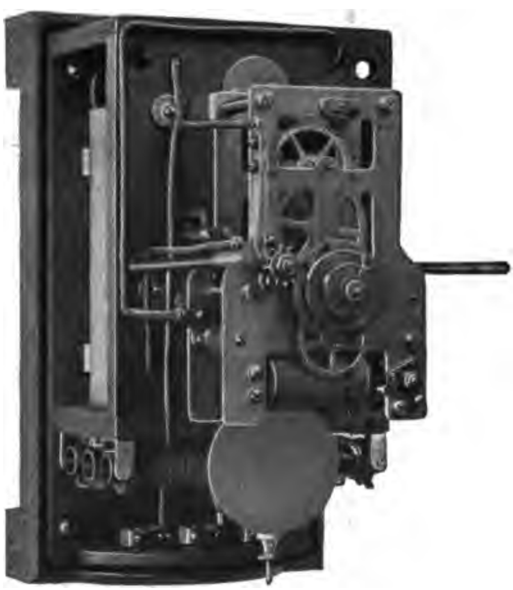

FIG. 261.

The estimate of the amount chargeable to a customer for the energy supplied is readily and simply calculated. The difference between the two meter readings, taken at the commencement and the end of a quarter, gives the units to be charged for at the high rate. The number of units multiplied by the high-rate charge will, therefore, represent the amount of the consumer's bill.

This can be easily shown as follows:—

Let n_1 denote the actual number of units consumed during the high-tariff periods of a quarter; n_2 denote the actual number of units consumed during the low-tariff periods of the same quarter; N denote the total number of units registered by the two-rate meter in this time; n_3 denote the number of these units registered by the meter during the low-rate periods of the quarter; c_1 denote the high-tariff charge per unit; c_2 denote the low-tariff charge per unit; A denote the amount of the bill.

$$\text{Then} \qquad A = c_1 n_1 + c_2 n_2$$

$$= c_1\left(n_1 + \frac{c_2}{c_1} . n_2\right) \qquad \text{(i)}$$

$$\text{Also} \qquad N = n_1 + n_3 . \qquad \text{(ii)}$$

Since the meter runs during the low-tariff periods at a speed reduced in the ratio of the low to the high tariff,

$$n_3 = \frac{c_2}{c_1} . n_2 . \qquad \text{(iii)}$$

From (ii) and (iii) it follows that

$$N = n_1 + \frac{c_2}{c_1} \cdot n_2,$$

and, therefore, inserting this in (i),

$$A = c_1 . N.$$

Hence the cost of the energy chargeable to the consumer is the product of the units, as registered on the dial, multiplied by the established or high rate per unit.

The Hookham Two-rate Meter is the ordinary continuous, or alternating,

FIG. 262.

current meter, modified as regards the integrating mechanism only, and is used in connection with a time switch. Fig. 262 is a front view of the instrument for continuous currents. In either case it is fitted with two sets of dials, the lower one of which registers the ordinary, or low-tariff, units, and the upper one the units consumed at the high rate of charge. A small index finger indicates by its position on the face of the dials which set is in operation, and the nature of the tariff. The change-over from the lower to the upper dials is made electrically by means of a solenoid, controlled by a time switch, the solenoid being placed as a shunt direct across the supply mains.

It will be seen from what follows that this shunt circuit only takes

current during the time when the high rate is effective, so that the energy loss due to it is small. The general arrangement of the solenoid and change-over gear is clearly depicted in Fig. 263, which gives a diagrammatic representation of the meter. The solenoid L is contained in a small box K, which is

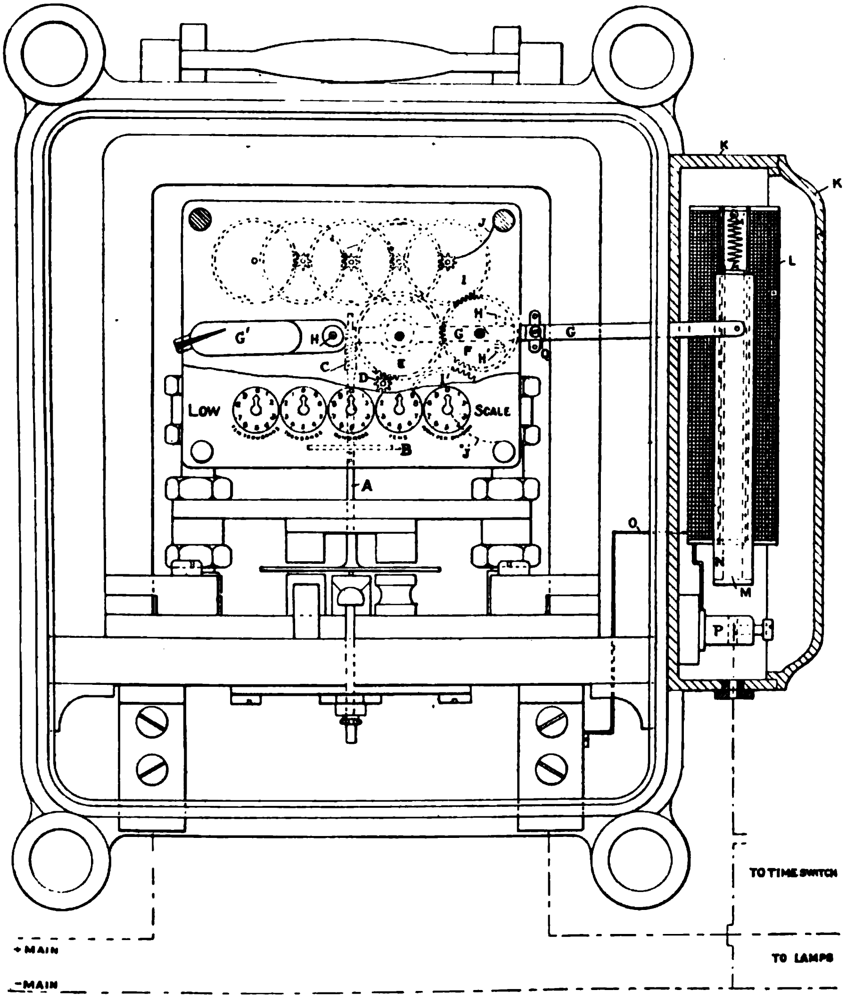

FIG. 263.

fixed to the meter case, and its core M is suspended within the coil by the spring M′. At its lower end the core carries the U-shaped iron strip N, by means of which it is attached to the rocking bar G. This bar G is pivoted at H, and carries the driving wheel F, which is always in gear with the wheel E, and, according to the position of the beam, meshes either with the first motion wheel I′ of the lower integrating train, or with the first motion wheel

I of the upper set of dials. The armature revolutions are conveyed in the ordinary manner from the worm on the armature spindle A to the horizontal wheel B, and through the worm on the spindle of the latter to the pinion D by means of a second wheel and pinion not shown in the diagram. The pinion D drives, through the wheels E and F, either the top or bottom registering train. The beam G also carries the counterweight G′ and the index pointer, and its motion is limited by the stops H′H′.

During the low-rate periods no current flows through the solenoid, and the tension of the spring and the weights of the core and of the counterbalance

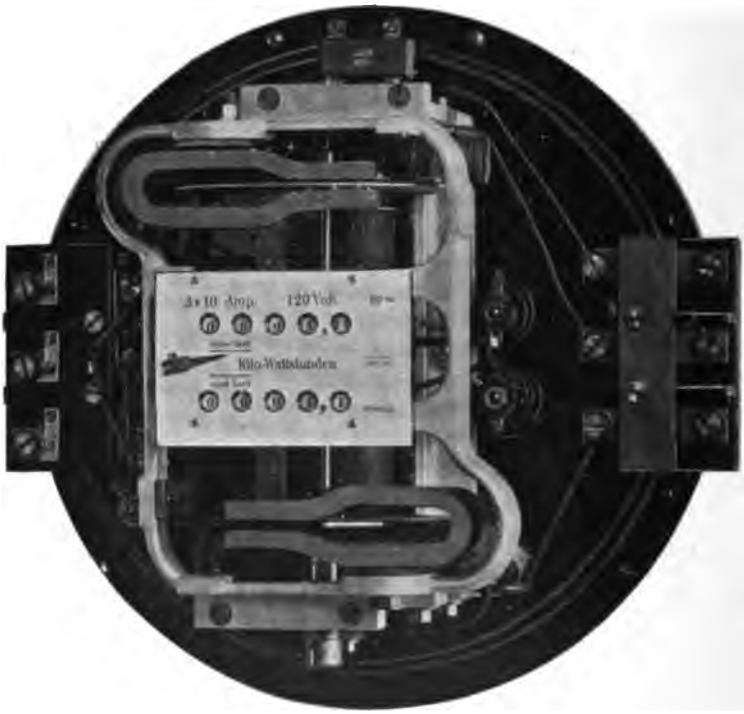

FIG. 264.

are so adjusted that the beam throughout this time rests against the lower stop H′. In this manner the wheel F meshes with I′, and the revolutions of the meter are transferred to the lower set of dials, and the low-rate units are registered. When the high-tariff time commences, the time switch closes the solenoid circuit, the core is sucked up into the solenoid and held there, and causes the driving wheel to engage with the first motion wheel I of the upper dials, which then register the units consumed at the high rate. This continues until the termination of the high-rate period, when the shunt circuit is opened and the rocking arm falls by gravity back to its original position, so that the driving wheel is again in mesh with the low-rate dials.

Siemens-Schuckert Double-tariff Meter.—In Fig. 264 is given a view of the Siemens-Schuckert three-phase meter, type F.U., adapted to double-tariff

purposes. The meter differs only from the ordinary type, described on page 203, in having two sets of counting mechanisms and a change-over gear, actuated by a double electro-magnet, which, in turn, is controlled by a time switch. The one counter registers the units at the low rate and the other at the high rate of charge, and the connection between the meter spindle and either train of wheels is made by the change-over device. This latter is, of course, applicable to any of the type of continuous and alternating current meters manufactured by this company. A pointer on the front of the dial face very clearly indicates by its position which counter is registering, and at which tariff. The time switch is separately illustrated in Fig. 265, and is a pendulum clock, fitted with an electrical self-winding gear. The method of operation will be readily followed by reference to these illustrations and to the diagrams in Figs. 266 and 267, of which the former is a diagrammatic representation of the change-over contacts of the clock, and the latter a diagram of connections for a two-wire continuous-current double-tariff meter. The dial of the clock is furnished with two sets of holes; those in the outer circle are for setting the commencement and those in the inner circle for setting the end of the tariff period, by means of two milled-headed, change-over pins inserted in them.

At the right-hand end of the edge of the base of the clock is a stationary red pointer (not shown in the illustrations), to which the clock is set to the actual time by rotating the time dial in a clockwise direction. When the clock is going the dial rotates, and with it the milled-headed, change-over pins, and these in turn come into contact with a small lever K (Fig 266) on the axle of the change-over lever U, which is moved either to the right or to the left. The two arms of this lever U each carry a small half-round pin. As either arm of the change-over lever U impinges against the contact balance lever W, its half-round pin first strikes against and slides on the flat ebonite surface $a\,b$ of the balance lever W, and after a short interval makes contact with a metal strip on the balance lever, and closes the circuit of one or other of the electro-magnets of the counting trains of the meter. The pin then breaks contact, and continues sliding for a short time on the curved surface

FIG. 265.

of the balance lever, tilting it until it is rapidly drawn over to the other side by means of a spring. The counter, which by this operation has been brought into gear with the meter spindle, registers until the second electro-magnet is energised in a similar manner. The meter is thus made to drive one or other of the two counters according to the setting of the clock, and it will be seen that the electro-magnets, through the agency of which this result is effected, are only energised for a short time in this way, so that they do not take current continuously.

The time switches are so arranged that, when they have been uninterruptedly connected to the supply for four to six days, they will keep going for twenty to thirty hours after the pressure circuits have been disconnected. If they be then again placed in circuit, the clock spring will be re-wound automatically by the electric winding gear of the clock. If, however, the interruption of the supply be of such a duration that the clock finally stops, it must be re-started by hand by pressing downwards the winding lever A (Fig. 266) about twenty times, each time allowing it to

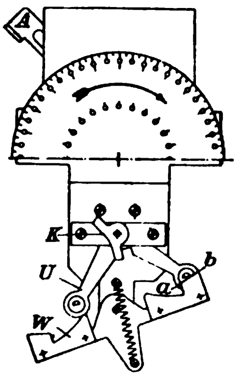

FIG. 266.

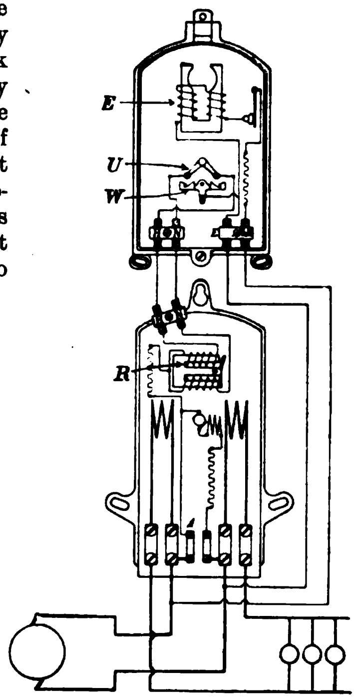

FIG. 267.

return to its initial position, when the pendulum is set swinging. The winding lever A is not used to re-start the clock if it has stopped through any cause other than a long interruption of the circuit.

Referring to the diagram of connections (Fig. 267), E is the electric motor which winds up the clock, U is the change-over lever, and W is the contact arm of the time switch. R is the double relay which actuates the counters of the meter, which in the diagram represents the continuous current type.

Fig. 268 represents a modified form of the time switch with electrical self-winding gear, and Fig. 269 is the hand-wound double-tariff clock manufactured by this company.

The Aron Two-rate Meter is a combination of an ordinary clock with an Aron meter, differing in no particular detail from the usual type.

The two instruments are in mechanical connection with one another, and are mounted together in one case, as illustrated in Fig. 270. The meter proper is furnished with two sets of dials, and a change-over gear fitted to them. By means of this gear, either the top or bottom set of counters will register according to the setting of the clock. The one set usually denotes the consumption during the evening-rate periods and the other that

Fig. 268.

Fig. 269.

during the day, when the lower tariff is in vogue. The total amounts of the energy delivered on each tariff are thus separately recorded, and the consumer can readily check the figures for himself. An indicator is also provided on the meter (seen in Fig. 270), and shows which set of dials is in use, and the whole arrangement is clearly visible through the windows. To the left of the meter (Fig. 270) will be seen the tariff clock. It operates the change-over gear on the meter dials. At the hour when the high tariff comes into effect it disengages the day-rate counting train from the main driving axle of the meter, and brings the latter into gear with the evening-rate counter;

at the hour when the evening rate ceases, it restores connection with the low-rate counter and disconnects the other set. The clock is electrically wound, but is not electrically connected with the meter proper. The face of the clock has five sets of dials, shown in Fig. 271. The centre dial is an ordinary twelve-hour dial. The top left-hand one has twenty-four divisions and revolves once in twenty-four hours, indicating whether the hours are those of the day or night. The right-hand one indicates seconds, and is for the purpose of facilitating the regulation of a number of these clocks.

The two bottom dials are for setting the tariff time. They have twenty-four divisions marked on them, and give the hours for day and night respectively. The pointers of these dials can be revolved in a counter-

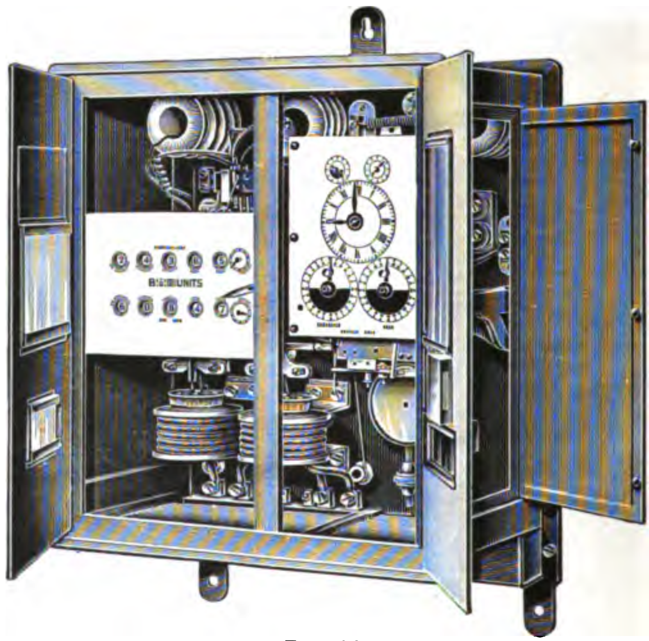

FIG. 270.

clockwise direction, and so set at any time by hand, the one on the left dial generally denoting the beginning and that on the right dial the end of the high-rate period. The night and day hours are distinguished by the black and white markings on the dial centres.

The Double-tariff Meters of the Compagnie pour la Fabrication des Compteurs, Paris, consist of their ordinary Thomson, O'K., and A.C.T. meters, each of which is fitted with a double-train gear, and is mechanically combined with a change-over clock situated at the top of the instrument.

In Fig. 272 is a view of this company's continuous current meter, type A, arranged in this manner for double-tariff purposes, very clearly showing the clock and the two dials, of which the one registers the low and the other the high rate units. These dials are differently coloured to distinguish between the tariffs, and a suitable indicator shows which dial is registering.

Figs. 273 and 274 are respectively a front and side elevation of their A.C.T. double-tariff meter, giving more in detail the construction of the clock and the change-over gear.

The clock, when fully wound, will run for thirty-two hours, and has two dials, of which the outer one A is fixed, and the centre one B is rotated by the clock mechanism once in every twenty-four hours. The night portions of the dials from 6 o'clock p.m. to 6 o'clock a.m. are coloured black, and half- and quarter-hour subdivisions are marked on them. The hour hand E is fixed on the centre dial B by the two brass knobs F and F'; it indicates at every moment on the outer dial A the actual time. The tariff time is set on B by

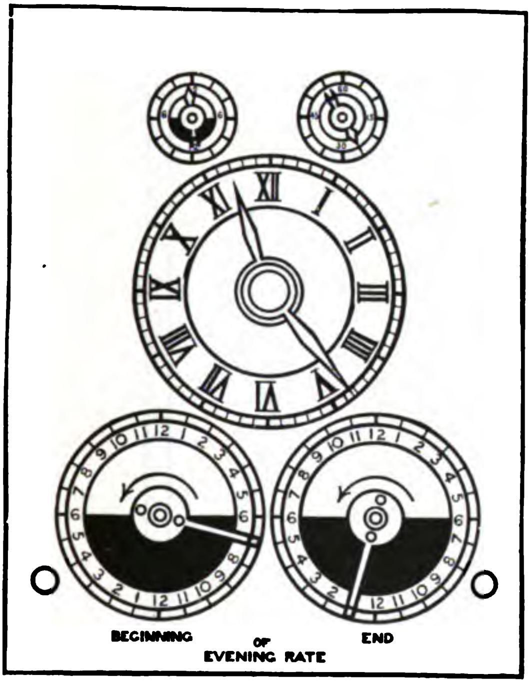

Fig. 271.

Fig. 272.

means of the two levers L and L′, situated in the annular space between the two dials.

They are lightly pivoted on the centre axle C of the clockwork and rotate with the dial B, their position relatively to which can be altered at will to make any change in the tariff period.

At the instant when the hour hand E passes the time on the outer circle A corresponding to the appointed hour for the change in the tariff, as indicated on B by one or other of the levers L and L′, the heel of this lever impinges with its inclined surface on the knob S carried on the top of the stirrup P. This stirrup, together with the rocking bar G, is pivoted on the horizontal axle at D. A horizontal pin D′, between D and S and passing through the forked end of the bar G, rigidly connects the latter with the stirrup. Two springs R

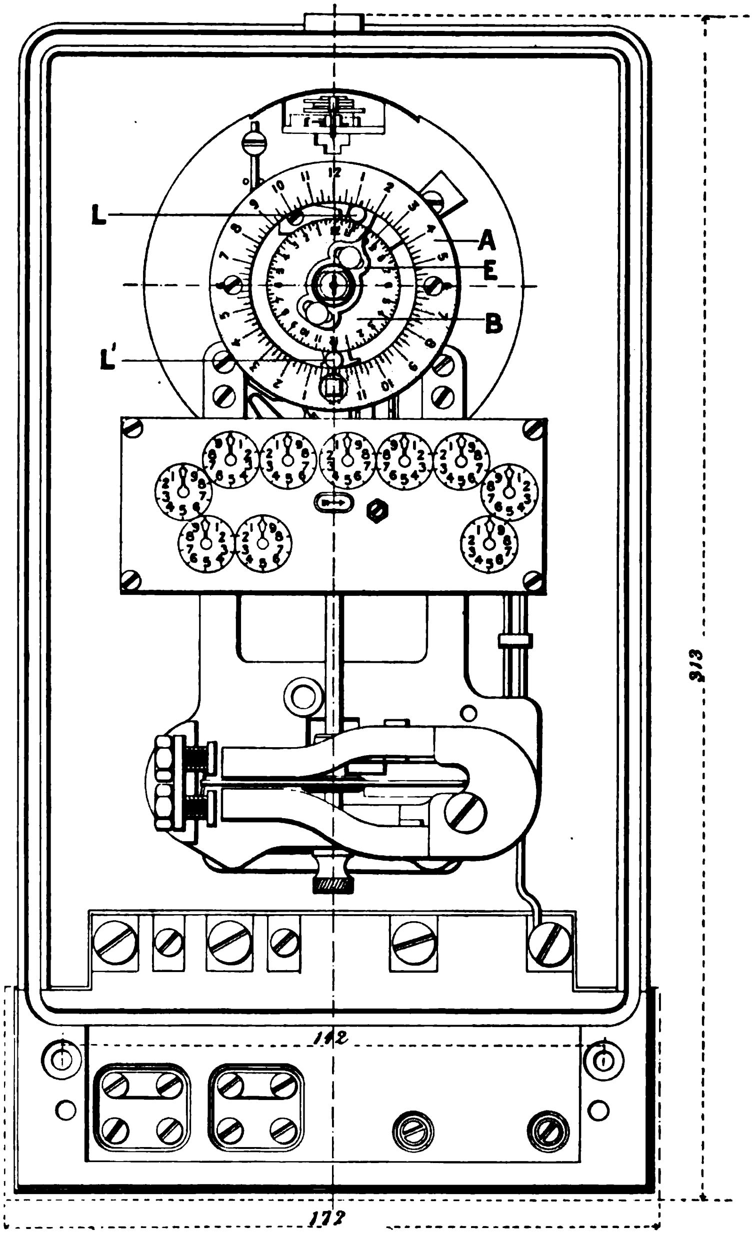

FIG. 273.

and R′, both of which are visible in Fig. 275, are attached at the one

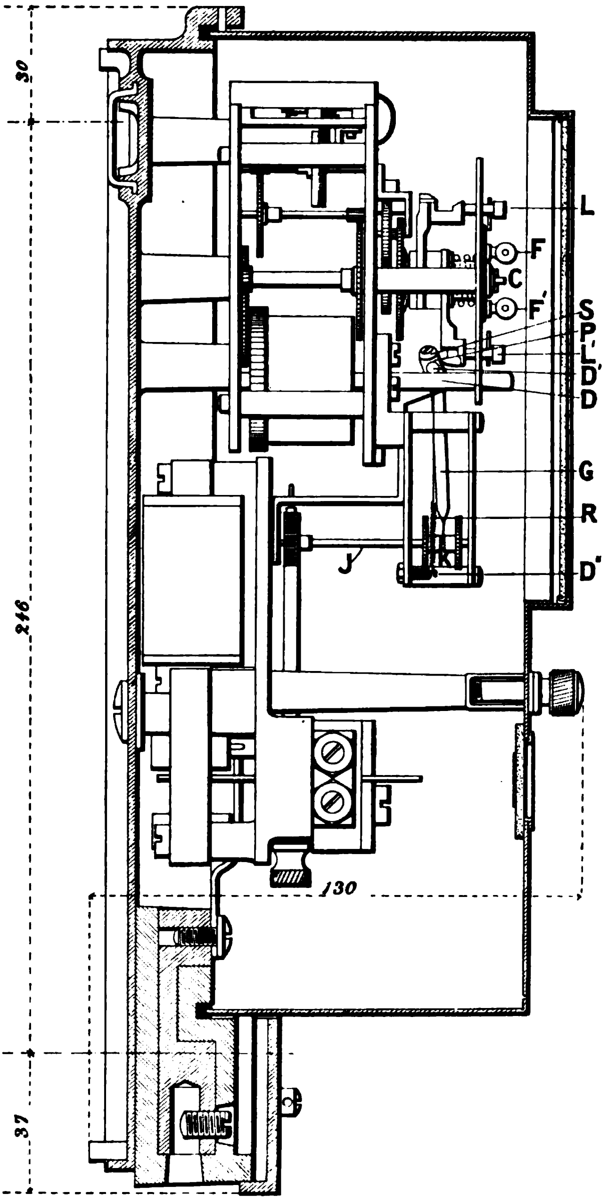

Fig. 274.

end to P, above the pivot, and at the other end to D″. The knob S is slowly tilted by the heel of the lever L, or L′, and the springs R and R′ become

stretched, the rocking bar G remaining stationary until the pin D′ has crossed the vertical plane passing through D and D″. As soon as this happens, the springs suddenly pull over the stirrup and with it the pin D′, which causes the rocking bar G to rapidly slide the two pinions at K along the spindle J, which is driven by the main meter axle. One or other of the pinions is thus caused to gear with a corresponding ratio wheel of one of the two integrating trains, and this counter will now register. When the hand E approaches the other limit of the tariff period, exactly the same action ensues; the other counting train will revolve, and the previously operative one will be disengaged from the meter proper.

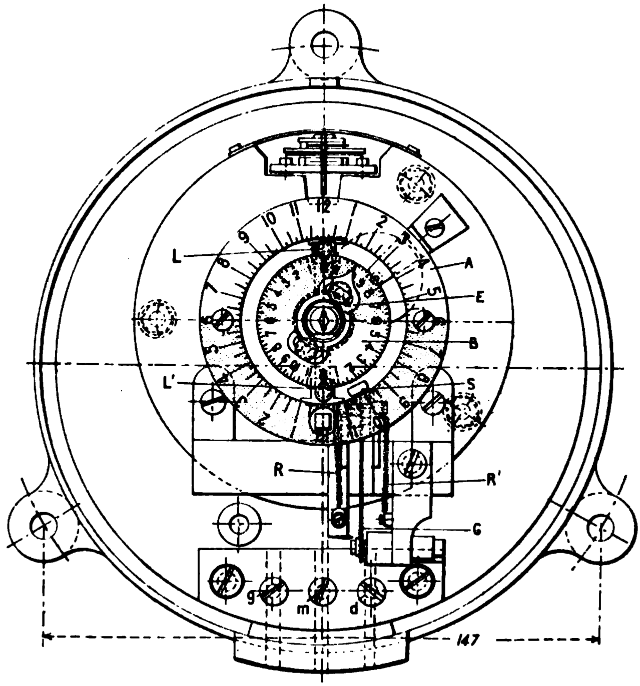

FIG. 275.

A very rapid and reliable change-over is effected in this manner.

This company also use a time switch to control either two meters or two groups of meters, so that the energy consumption is separately registered according to the time of day. The time switch is shown in Figs. 275 and 276, and its action and clock mechanism are exactly the same as in the description just given. Instead, however, of operating upon a mechanical change-over gear, the clock actuates a two-way switch, the rocking bar G now taking the place of a switch contact-arm. This copper arm G has a silver contact at its lower end, with which it bears on one or other of two silver contact studs, according to the direction in which it is moved. These two studs are connected to the terminals *g* and *d* of the time switch, and the terminal *m* is joined to G.

Above the studs are two small silver strips, which make a spring connection between the studs and the switch arm to ensure good contact and to avoid sparking.

The connection between the time switch and the meters which it controls is made by joining the shunt terminals of the meters of the one group and those of the other set to the terminals *g* and *d* respectively, the middle terminal *m* being connected to that supply main which does not pass through the meters.

If the contact arm be on one of the studs, say that one connected to the terminal *g* of the time switch, the meters, the shunts of which are connected to *g*, will register, and those connected to *d* will stop, as their shunt circuits will be broken. When the arm passes to the other contact stud, it will open the shunt circuits of the meters which have just been registering, and will close the circuits of those which have now to operate.

The Bat Meter Company, the British Thomson-Houston Company, and the Danubia Actiengesellschaft, Vienna, use exactly the same mechanical combination in connection with their two-rate meters, and the time switch for electrically operating two systems of meters.

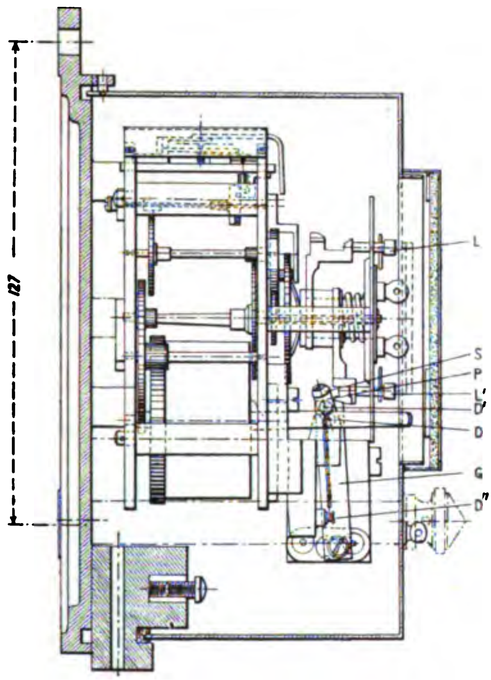

FIG. 276.

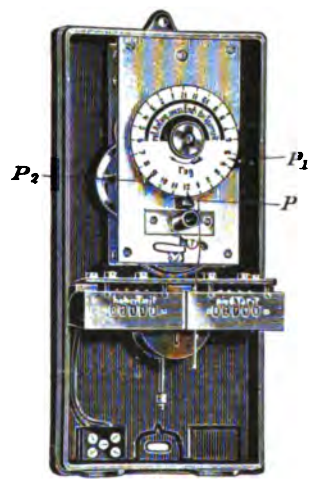

FIG. 277.

Luxsche Industriewerke Double-tariff Meter.—For a two-rate system in which the high-rate and the low-rate units are separately registered, the Luxsche Industriewerke, Munich, manufacture a special double-tariff instrument, which is used in electrical connection with any type of motor meter. This two-rate instrument is illustrated in Fig. 277, and consists of two integrating counters, an electro-magnetic relay, which actuates a driving pinion or train of wheels, and a time switch, by means of which the pinion or train is caused to gear alternately with one or other of the two counters, according to the tariff in vogue. To adapt the meter proper for use with the

apparatus, it is only necessary to provide the armature spindles with a non-sparking contact device, and to remove the ordinary counting train.

The method of operation is very simple. Each time the meter has executed a definite number of revolutions the contact maker is closed, when the relay becomes energised and actuates the integrating counter to which it happens to be connected. In this manner the revolutions of the armature spindle are conveyed to one or other of the two integrating mechanisms and

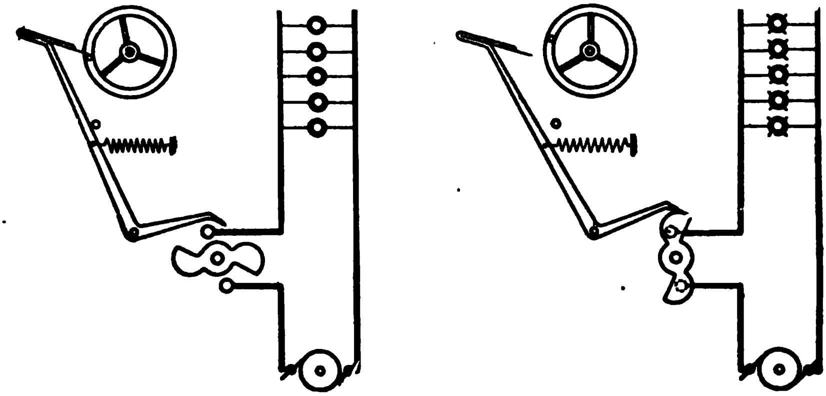

FIG. 278.

the units registered. The contact maker is closed for a very short interval only, when it is again broken, so that the energy consumption is small. The interchange between the relay mechanism and either counter is effected mechanically by the time switch, which is arranged either as a hand-wound 45-day clock, or is fitted with an electrical, self-winding gear.

Referring to Fig. 277, P_1 and P_2 are the two tariff pointers, which rotate with the central dial, but can be moved relatively to it for setting the commencement and termination of the special tariff time. P is the stationary hand for reading the time of day, and the clock is set by rotating the dial until the correct time appears opposite the pointer.

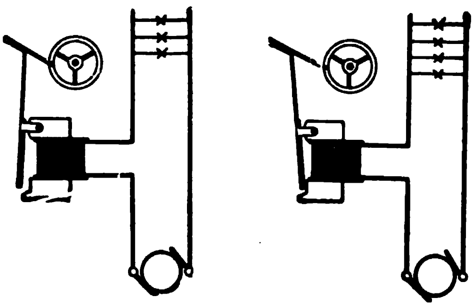

FIG. 279.

Hour Meters. — An hour meter consists simply of an ordinary hand-wound, balance-wheel clock, the function of which is to register on a dial the hours during which current flows in an installation to which it is connected, irrespective of the magnitude and variation of the current or voltage. The escapement of the clockwork is held either mechanically or electrically until the passage of a current, when it is freed, and the clock will then go in the ordinary manner until the current is interrupted, when it again stops.

Fig. 278 is a diagrammatic representation of a mechanically controlled

hour meter, the diagram on the left showing the escapement prevented from going when the switch is off, that on the right showing the switch closed and the balance-wheel free to move.

In an hour meter with electrical control the balance-wheel is, in general,

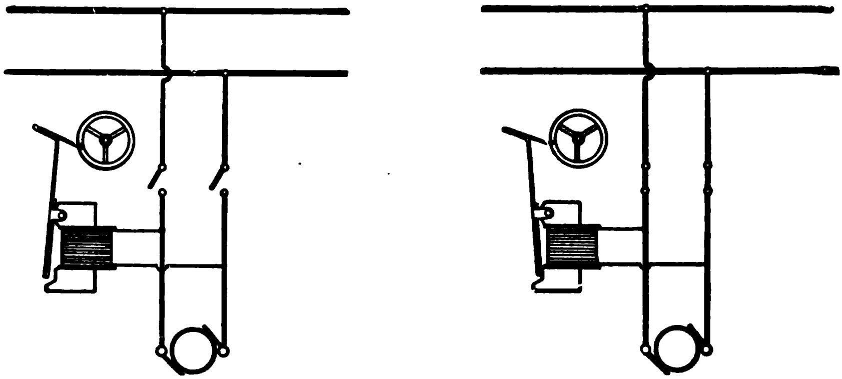

FIG. 280.

arrested and freed by the action of an electro-magnet, and in such a manner that the clock only goes when the electro-magnet is energised by the passage of a current.

The electro-magnet is either series-wound or shunt-wound. The series-

FIG. 281.

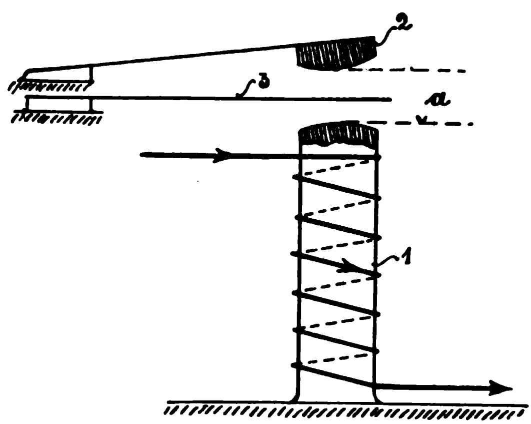

FIG. 282.

wound electro-magnetic type is usually used for lighting circuits, and the method employed is shown in a general manner in diagram (Fig. 279).

Fig. 280 represents diagrammatically the shunt-wound electro-magnetic hour meter, showing also the conditions which obtain with the motor shut down and working. An external view of the Electrical Company's electro-

magnetic type of hour meter is given in Fig. 281, and, in general, a ratio of 1 : 10 is employed between the starting current and the maximum of the installation; that is, in a 5-ampère circuit the clockwork of the hour meter will be released on the passage of a current of 0·5 ampere. The starting current can, of course, be made smaller if necessary.

In some instances the clockwork is driven direct by the current, in which case the hour meter is always furnished with a pressure winding.

To eliminate the effect of hysteresis, the Deutsch-Russische Elektricitätszähler-Gesellschaft, Germany, use a spring attachment with the electro-magnet controlling the hour meter. The principle will be understood by

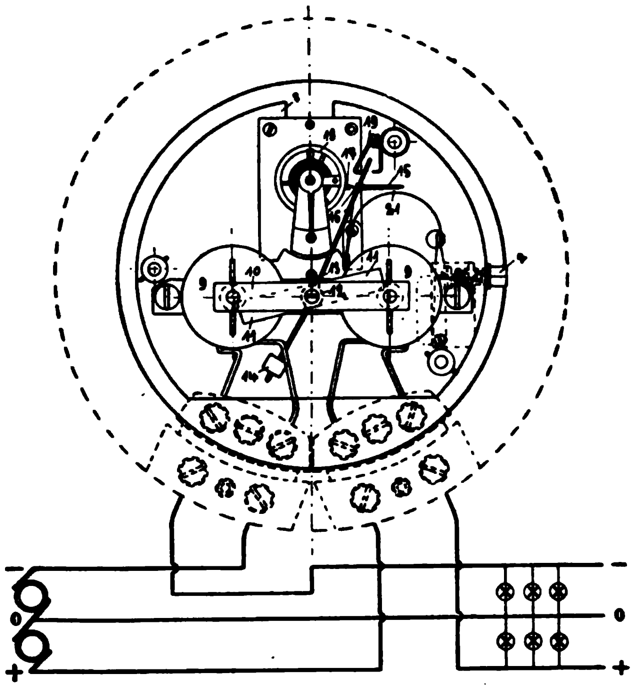

FIG. 283.

reference to Fig. 282. A small spring is interposed about midway between the extreme position of the armature of the electro-magnet and the latter. This ensures the prompt release of the armature when the current falls to a certain value which it had when the electro-magnet first attracted it. Supposing that this attraction takes place when the current is 2 amperes, no further motion of the armature will ensue with an increasing current. When, however, the current again drops to 2 amperes, the armature will not necessarily be released, owing to the effect of hysteresis, in consequence of which the force exerted by the electro-magnet does not drop off proportionately with the decreasing current. To prevent any uncertainty of action due to this cause, the tension of this spring is so adjusted that the counter-force it exerts just balances the hysteresis effect, so that with decreasing current the armature will be released when the current has fallen to the initial value at

which the magnet with increasing current attracted it. Fig. 283 illustrates the method of applying this principle to their three-wire hour meter. The escapement 18 of the clock is normally held by means of a light hairspring 16 attached to the lever 13, which, in turn, is pivoted on the axle 12 of the armature 11 of the electro-magnet. When the coils 9 of the electro-magnet are energised on the passage of a current, the lever 13 frees the escapement, due to the attraction of the armature by the electro-magnet, and slightly compresses the spring 21. The clock can now go, and the hours are registered during which current is taken. When the current drops to its initial value at which the armature with an increasing current was attracted, the spring 21 comes into play, the armature is at once released, and the clock again stops.

CHAPTER XIII.

SOME MECHANICAL FEATURES IN METER DESIGN.

General Mechanical Design—Shafts and Pivots—Pivot of Meter of General Electric Co., U.S.A.—Spindle and Pivot of A.C.T. Meter—Detachable Armature Shaft and Pivot of Duncan Meter—Meter Bearings—Ball Bearing of Electrical Company's Meters—Ball Bearing of Scheeffer Meter—Ball Bearing of Westinghouse Meter—Jewel Bearing of Thomson Meters—Bearing and Combined Locking Device of Siemens-Schuckert Meters—Duncan 'Visual' Bearing—Stanley Magnetic Suspension—Stanley Rotated Jewel Bearing—Evershed Magnetic Suspension—Upper Bearing—Integrating Mechanisms—Dial Register—Cyclometer Counter—Aron Spring Cyclometer Counter—Siemens-Schuckert Weight Cyclometer Counter.

General Mechanical Design.—The suitability of an electricity supply meter to act as a commercial measuring instrument depends both on its electrical and mechanical design, and, in general, the mechanical features are quite as important as the electrical details of the meter. The electrical design naturally varies with the nature of the supply current, the pressure of the system, the system itself, the object of the meter, *i.e.* whether the meter is intended to function as an ampere-hour or watt-hour meter, and with the principle on which it works, namely, the electrolytic, the heating, and the electro-magnetic effect of a current. The electrical features have already been dealt with in the preceding chapters, in which are included descriptions of a large number of various types of supply meters in general use.

In the present chapter a few mechanical features, mostly applying to motor meters, are briefly discussed. A meter should be of simple and sound mechanical construction, to withstand ordinary handling and usage, so that it does not suffer injury during shipment, railway transit, or in its installation. It should, as far as possible, retain its original accuracy over a long period. Absolute permanency of calibration cannot be obtained, as it is impossible to eliminate friction entirely, or to prevent its gradual increase during the operation of the meter in house-service. These two important considerations mainly depend on the mechanical design. In addition, dust, insects, and moisture should be rigorously excluded, as otherwise, whatever the merits of the electrical design, the meter will rapidly deteriorate. This last condition is, in general, fairly well satisfied in most well-designed meters.

The various elements of the meter are fixed in a substantial case, or are mounted on a base plate, and are completely enclosed in a protecting cover. The cover is either itself recessed, and the groove lined with felt, rubber, or other suitable material, or the base plate is provided with the channel in which the packing is laid, and the two should form together a moisture-, insect-, and dust-proof joint, when the cover is properly secured by the holding-down screws, and sealed.

The meter is always provided with two separate covers; the one is the main meter cover, and the other is to protect the terminal chamber and to give access to the terminals without removing the main cover. They are each furnished with an efficient and independent sealing arrangement. The main cover has two windows, of which the one is for reading the dials, and the other enables the speed of the meter to be checked by observing the revolutions of the brake disc on the spindle. In commutator motor meters a third cover should be provided to give access to the commutator and brushes, for the purpose of inspection and cleaning.

In the meters of the British Thomson-Houston Company, the Compagnie pour la Fabrication des Compteurs, Paris, and of the Danubia Actiengesellschaft, Vienna, the commutator and brushes are situated at the lower end of the meter spindle, and, together with the jewel step-bearing, are protected by a cap, which is secured to the main cover by a bayonet catch, and is independently sealed. In the Vulcan meter the commutator and brushes are arranged at the upper end of the spindle, and are also protected by a separate cover in the shape of a dome with independent sealing.

The Stanley Instrument Company, U.S.A., use an all-glass cover for the meter proper in their type H induction meters. A thick, strong glass cover is secured to the iron base, and sealed in the same manner as the metal cover. It is imbedded on a gasket, making an air- and dust-tight joint. The meter is connected to the circuit without opening the main cover, through which all the working parts are readily visible. Glass covers are also employed by the Westinghouse Electric and Manufacturing Company, U.S.A., who also seal their meter, and accept no responsibility if the seal be broken. The Sangamo Electric Company, U.S.A., permanently seal their meters, and it is not intended that the cover should be removed from the meter under any circumstance. The cast aluminium case fits in a deep groove in the cast-iron base, and a cementing material is put into this groove, sealing the case and back together watertight. All openings and joints are also carefully sealed. The holes through which the connections run from the terminal chamber into the meter proper are filled with rubber gaskets, and the wood block holding the connecting pieces presses a thick layer of felt tightly against the wall between it and the interior of the meter. The dial window and observation window are also sealed, and all holes drilled through the back of the meter to receive screws are likewise sealed with plaster of Paris and stamped, to prevent tampering.

The whole meter should be light, compact, and portable, to facilitate testing and handling. It is, however, most important for the cover and case to be strongly made, so that they effectually protect the meter from mechanical damage, even if an increase in the total weight of the meter should hereby be incurred. This fact was most forcibly brought home to the author. Amongst many manufacturers who very courteously supplied the author with meters for inspection and testing, Messrs Ferranti, Ltd., forwarded a sample of each of their alternating and direct current types. Each meter was most carefully packed in a very strong case. Nevertheless, the box containing the alternating current meter arrived practically broken in two halves, but the meter itself, owing to its sound mechanical construction, was not in the least damaged or affected. This may have been a case of exceptional carelessness on the part of the carriers, and has only been cited to show that such accidents can and do happen, and to emphasise the importance of a strong mechanical meter. Continental meters differ in this

respect materially from English and American meters, those manufactured on the Continent being provided with covers of very neat appearance, but they are, in general, far too flimsy.

The position and arrangement of the terminals differ in different types, and are, in general, readily recognisable from the illustrations accompanying the descriptions given. In a two-wire energy meter four terminals should be used, *i.e.* two shunt and two main current terminals. The common shunt and main current terminals should be connected through a small copper bridge or hook, so that the pressure circuit of the meter can be entirely isolated without having to remove the main cover or disturb any of the internal connections of the meter, to facilitate testing, which is especially important when several meters are tested in series. The terminals should be carefully insulated from one another by means of non-hygroscopic and fire-proof insulation, and those of opposite polarity separated by mechanical division walls.

The method of connection is also of importance, and should be both convenient and simple, so as to avoid the possibility of mistakes; it should be impossible in the case of an energy meter for the connections to be so made that the pressure current flows through the main circuit of the meter, and, further, the design should be such as to preclude tampering with the meter by unauthorised persons. The method of hanging used in the British Thomson-Houston meters is of interest in this latter respect. At the back of the meter is a special suspension-piece, by means of which the meter is hung on a supporting screw. After the meter has been levelled, it is securely fixed by means of two screws, which pass through holes in the meter base, access to which can only be had by removing the terminal cover. When the meter has been placed in position, connected to the circuit, and sealed, it is impossible to change its level without breaking the seals. If this could be done, as with exposed holding-down screws, unless sealed, the level could be altered and the meter made to run slow and under-register.

Shafts and Pivots.—In general, the meter shaft is made of a light steel spindle, having a detachable pivot at its lower end, which is removed by unscrewing it from the shaft or spindle proper. The end of the pivot is highly polished and made glass-hard, in many instances being ball-shaped, and forms the actual bearing contact of the spindle with the bottom step-bearing. As a rule, when the jewel of the step-bearing becomes defective and requires renewing, the pivot is also found to be roughened or damaged. A new pivot should be inserted in the meter when a worn jewel is replaced, whether the shaft end is damaged or not. It is important that the worm on the spindle should not be liable to rust, due to moisture, etc., and so increase the friction between the axle and the integrating train, and in many instances it is made of brass.

Pivot of Meter of General Electric Co., U.S.A.—The General Electric Co., U.S.A., use a brass pivot with a steel bearing surface, as it is often found that the shaft of the meter becomes more or less magnetised, and with a steel shaft end some difficulty is experienced in the removal of a screwed pivot. The brass pivot has forced into its one end a small piece of high-grade piano wire, which is hardened glass-hard and highly polished, and forms the actual bearing surface with the jewel.

Spindle and Pivot of A.C.T. Meter.—In the A.C.T. meter the spindle is of German silver and a small steel pivot is screwed in the lower end, and a

steel pin forms the upper guide bearing. German silver is used to prevent the worm from rusting.

Armature Shaft and Detachable Pivot of Duncan Meter.—The Duncan Electric Manufacturing Co., U.S.A., use a hollow, nickel-steel spindle and a detachable pivot of steel piano wire, which is not threaded, but is held in the lower end of the spindle by magnetic attraction, the meter shaft being magnetised for this purpose. This magnetised pivot can be removed from the meter very quickly with a pair of ordinary pocket tweezers. The renewal or insertion of a new pivot is further reduced to a very simple operation in connection with the special visual bearing, characteristic of the Duncan meter. Some further important improvements have been recently introduced by this company in connection with the manufacture of meter shafts, which are made detachable in sections for the purpose of quickly renewing the worm, commutator, and the armature.

One of these shafts is shown assembled in Fig. 284, and the details of its component parts are given in Fig. 285. The sections screw into one another and are all made to gauge, so that they are quickly and readily replaced. To facilitate building up or dismantling the shaft, both the worm part W and the commutator part C are provided with knurled portions, by means of which they can be screwed into one another and into the main body of the shaft B, on which are mounted the armature near its upper end, and the brake disc near its lower end. P is the threadless bearing pivot. In the description given of the Duncan meter in Chapter IV., the very ingenious method of connection used between the commutator and the armature has been explained and illustrated. It allows either the armature or commutator to be removed and a new one to be inserted without having to un-solder or re-solder any connections. By making these parts detachable and interchangeable in this manner, labour and time are saved in effecting meter repairs.

Meter Bearings.—Two methods of supporting the revolving element of a meter are in general use. The shaft either runs in a jewelled step-bearing or a special ball bearing. A ball bearing does not decrease initial friction, all other things being equal; in fact, the friction is higher than in the case of a point pivot on a jewel. A ball bearing, provided that it is flexibly supported, is, however, preferable to the ordinary jewel bearing with a pivot, as the bearing friction is less liable to change than with the latter type.

Ball Bearing of Electrical Company's Meters.—In Fig. 286 is illustrated the ball bearing used by the Electrical Company, Limited, London, in their various meters. The end of the armature spindle is cupped and highly polished, and rests on a small ball, which in turn bears on the polished jewel of the bearing. The bearing, as a whole, is flexibly supported on a stiff spring, which is sufficiently elastic to give under a heavy shock.

Ball Bearing of Scheeffer Meter.—A ball bearing is also used to support the rotating element in the Scheeffer meter. Fig. 287 shows the ball resting on the jewel in the jewel screw, and by means of Fig. 288 the method will be understood of locking the meter spindle for transit and for the purpose of inspecting or renewing the steel ball or the jewel. The knurled nut A is screwed up until it lifts the armature disc and locks it. This secures both the disc and shaft. The jewel screw B can then be unscrewed and taken out. Care must be exercised in removing the jewel screw to hold up its point so that the steel ball rests in the cup.

Ball Bearing of Westinghouse Meter.—The cup and ball bearing in the

Westinghouse meter is also illustrated diagrammatically in Fig. 289. A

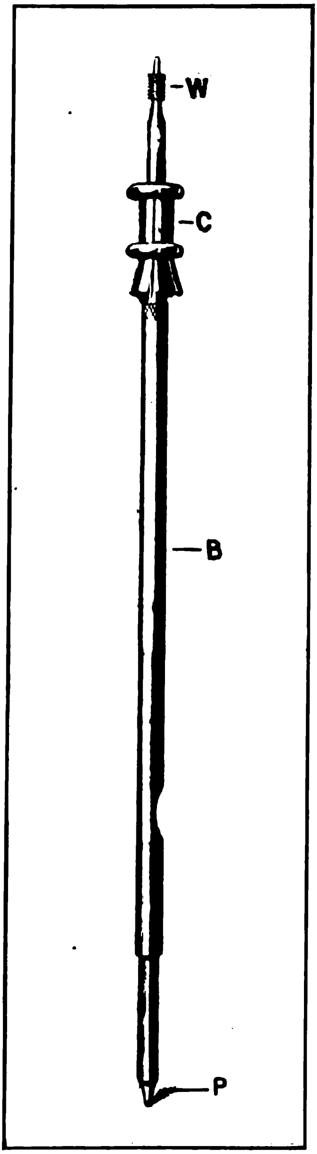

FIG. 284.

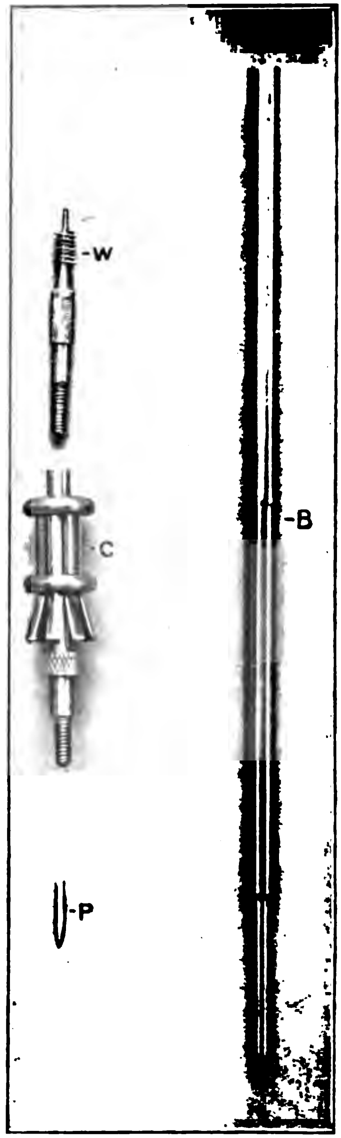

FIG. 285.

highly polished steel ball $\frac{1}{16}$ inch in diameter is used between two sapphire cupped jewels. The lower jewel is mounted in the usual manner in a jewel

screw, while the upper one is inverted and is set in a removable sleeve on the lower extremity of the meter spindle.

Jewel Bearing of Thomson Meter.—In general, the jewelled step-bearing used consists of a highly polished and cupped sapphire jewel, set in a plug, which is flexibly supported by a spiral spring within the jewel bearing-screw. The strength of the supporting spring beneath the jewel plug in relation to the weight of the rotating element of the meter is of importance in the life of the jewel. In the A.C.T. meter the spring just balances the weight of the armature disc and shaft with the driving worm. In this case no locking device is used, and the meter can be subjected to considerable shock without damage being done to the jewel or pivot. As a rule, an arrangement is fitted

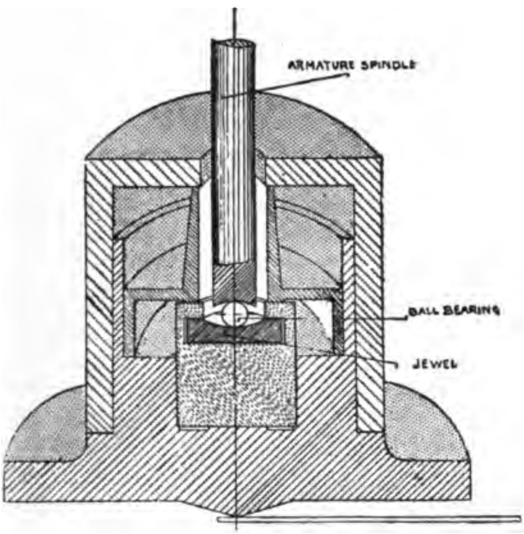

FIG. 286.

FIG. 287.

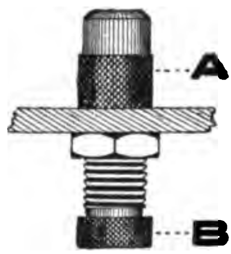

FIG. 288.

to the meter by means of which the shaft with the portions it supports is lifted off the jewel for transit, and firmly clamped against the top bearing-stud. Jewels should invariably be spring-seated, as they are far less liable to damage by a shock or jar, due to the pounding action of the shaft, than when rigidly mounted. Diamonds are also used by some companies for large capacity meters which have heavy moving elements and for tram-car work, when the meter is subject to considerable vibration. Diamond jewels are flat, and are set within a ring of sapphire stone to keep the pivot in the centre of the diamond. The general arrangement of the jewel bearing and locking device used in the Thomson meters will be readily understood from Fig. 290, which also shows the detachable spindle pivot.

Bearing and combined Locking Device of Siemens-Schuckert Meter.—Fig. 291 is an illustration of the excellent footstep-bearing and combined locking device used in the Siemens-Schuckert meters. In the figure, the shaft is shown in the locked position with the jewel screw lowered. H is a stationary

hollow bearing-post in which the jewel screw L moves, and is divided internally into two portions, separated by the division ring R, on the upper surface of which rests a spiral supporting spring. The top portion of the jewel screw, in which is set the sapphire jewel S, is completely covered by a tightly fitting cap C, in which is a small hole to allow the ball pivot of the shaft to pass through, so as to rest on the jewel when the meter is in operation. The cap C also forms a very efficient oil chamber, from which, owing to surface tension, the oil is unable to escape during the handling and transit of the meter. B is the clamping bush, by means of which the meter spindle is lifted out of the bearing. It has an internal thread in which the jewel bearing-screw works, and at its upper end it terminates in a conical opening. This clamping bush or sleeve can, moreover, only have a motion of translation, as it is prevented from turning by the guide-pin P.

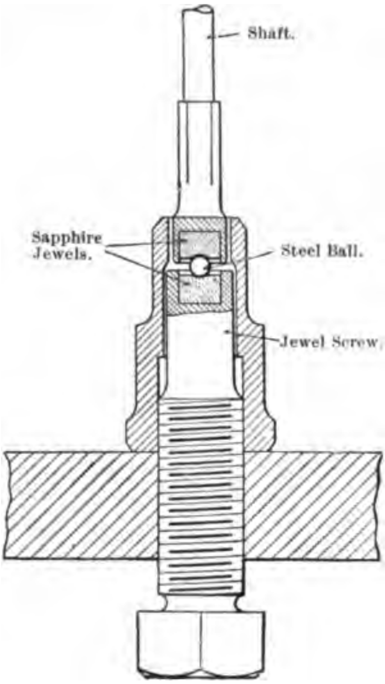

Fig. 289.

To clamp the meter, a screwdriver is inserted in the head K of the jewel screw, which is then turned counter-clockwise. The flange F of the jewel screw, in this position, rests against the ring R, so that when it is turned

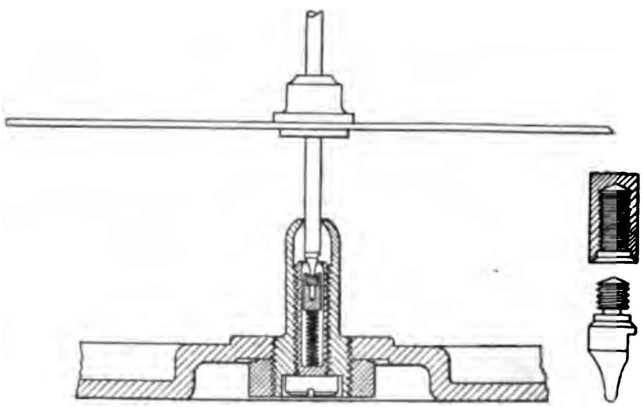

Fig. 290.

counter-clockwise the spiral spring which flexibly supports the jewel screw moves the clamping bush B in an upward direction. The upper coned portion

of the latter engages with the corresponding coned end of the boss of the disc, and the shaft is raised until its upper end is firmly pressed into the top guide-bearing. The revolving element is clamped in this manner. With further counter-clockwise turning, the jewel screw will unscrew itself from the sleeve B and will descend until its pin comes into contact with the small set screw T

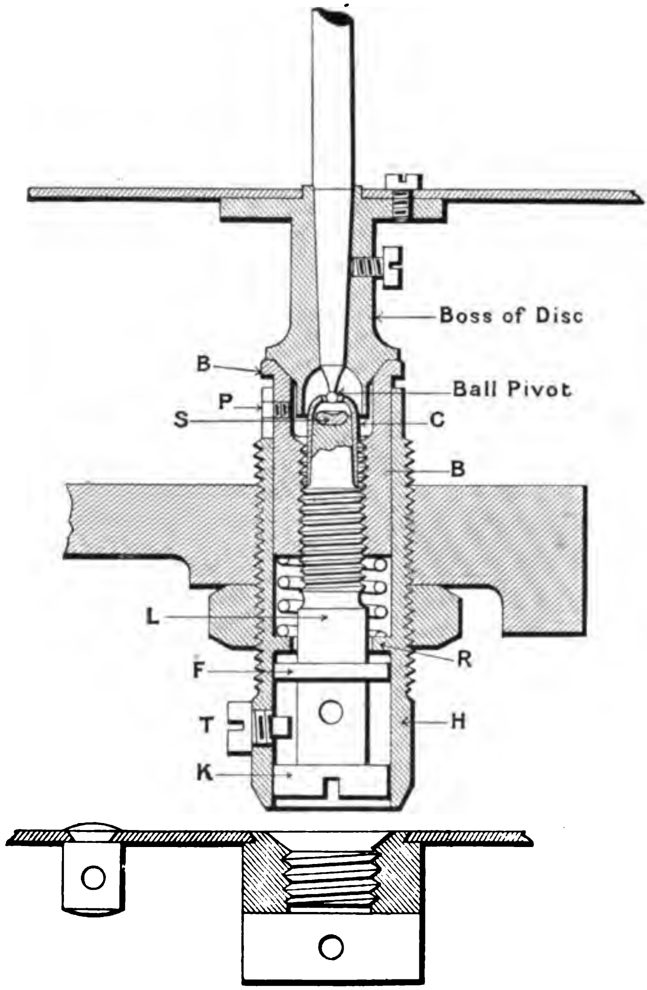

FIG. 291.

in the lower half of the bearing post H, when further motion is stopped. To completely remove the jewel screw for renewals or inspection, this set screw must be taken out. It will be seen that only one operation is necessary to clamp the meter and to lower the jewel away from the ball pivot, so that the two cannot come into contact through a jar or blow, and consists in always turning the jewel screw in one direction.

When the meter is to be used, the spindle is lowered on the jewel by turning the jewel screw in the clockwise direction; it first ascends until its flange F bears against the internal ring of the bearing-post H, on which the sleeve B descends and with it the spindle, until its pivot rests on the jewel. Access to the bearing can be had without removing the main cover of the meter, by removing the sealing screw from the hole in the cover below the jewel bearing. A screwdriver can then be inserted through this hole and the above operations carried out.

In Fig. 292 is a sectional drawing of the latest type of Siemens-Schuckert footstep-bearing, differing in some details from the one just described. The shaft A has in this case a detachable, threadless ball pivot Z, which, in the working position of the meter, rests on the sapphire jewel B in the jewel screw F. The top of the jewel screw is fitted with a small cap H, which forms an oil chamber for the ball pivot, the opening of this chamber being just large enough to prevent the escape of any oil through shocks or jars. The jewel screw F works inside the bearing-post K, which is secured to the base of the meter by the lock-nut M. E is a movable sleeve, within the bearing-post K. This sleeve is pressed in the upward direction by a spiral spring S, and is prevented from turning by a pin R. It has a small bush D attached to it, on the curved edge of which the pin T of the jewel screw F rolls on the rotation of the latter. In this manner the sleeve E is held down as long as the armature is free to rotate, when the head of the jewel screw F rests against the bearing-pillar K.

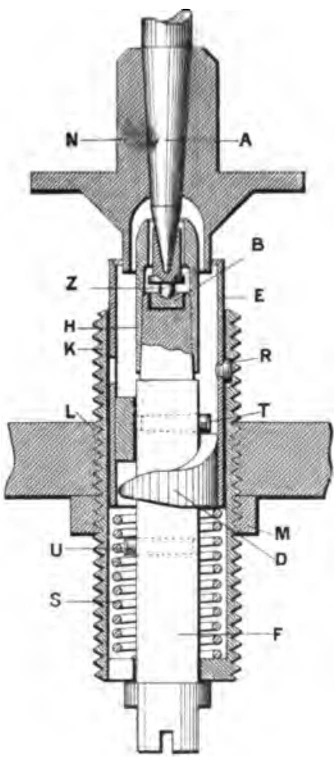

FIG. 292.

The moving element is locked by lowering the jewel screw, when the sleeve E, owing to the pressure of the spring S, rises, engages with the boss N on the shaft A, and forces the shaft against the upper bearing. As soon as this is accomplished, F will descend, if turned further in the same direction, until it reaches the stop U, in which position it is impossible for the shaft to press the pivot Z on the jewel B, although the armature during transit may be violently thrown downwards. It will be observed that the detachable pivot must move with the jewel screw in its descent. On continuing to turn the jewel screw it may be completely withdrawn from the meter, together with the pivot. The advantage of this form of construction is that the jewel screw and the pivot are simultaneously taken out of a meter without disturbing the main cover. The pivot and jewel can be readily examined, and both a new pivot and a new jewel screw can be inserted in the meter without the constant of the meter being changed, and consequently a re-calibration is unnecessary, as these parts are accurately made to gauge, and are interchangeable.

Duncan 'Visual' Bearing.—The visual bearing used by the Duncan Electric Manufacturing Company, U.S.A., represents a departure from the bearings in common use in meters. The jewel bearing-post is threadless, and can be readily taken out and inserted again without the aid of a screwdriver

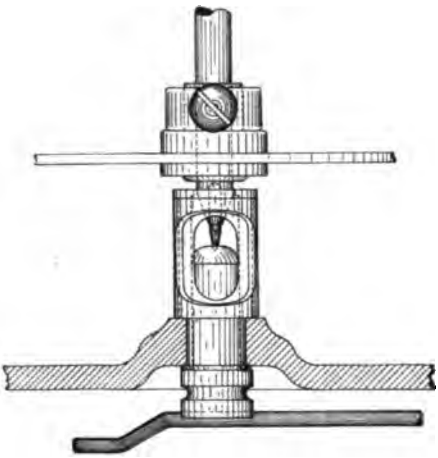

FIG. 293.

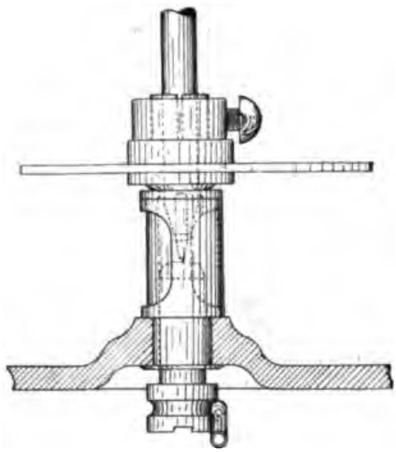

FIG. 294.

or any instrument, and the pivot and jewel can be examined during the operation of the meter. The construction of the visual bearing and threadless jewel post in the Duncan meter is illustrated in Figs. 293, 294, and 295. Fig. 293 is a front view of the bearing open, and Fig. 294 shows the bearing closed and the jewel post lowered for transit, while Fig. 295 is a sectional drawing giving the details of construction. The bearing is provided with a collar '8' on the jewel guide-post or support, which permits of an inspection of the jewel and the spindle pivot during the operation of the meter. When this collar is turned so as to expose the bearings, the detachable pivot may be removed with a small pair of tweezers, either through the opening in the collar or through the jewel post-hole in the shelf of the meter. The jewel post '12' is held in position against the point of the spindle by a phosphor-bronze wire

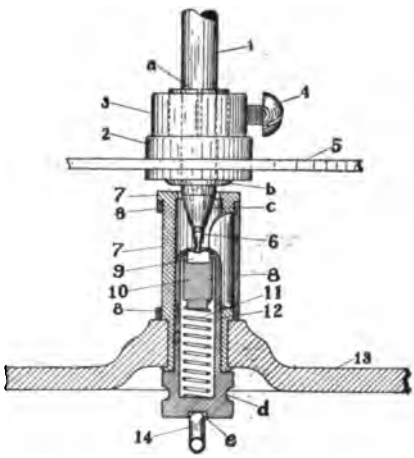

FIG. 295.

spring '14,' which fits in the slot '*e*' provided in the head of the jewel post. The pivot '6' bears on the jewel '9,' seated in the plug '10,' which is supported by the spring '11.' When the meter is being transported, the jewel post is lowered away from the spindle point, and the wire spring is placed in the groove '*d*' in the side of the head of the jewel post. When

installing the meter, the wire spring is simply drawn enough to one side to allow the head of the jewel screw to pass it and to clear the groove, when the jewel post is raised and the spring again inserted in the slot at the bottom.

Before removing the spindle pivot, the jewel post should be taken out to give more room in the operation. As already mentioned, the shaft is magnetised, and the detachable pivot is retained in position by magnetic attraction.

Stanley Magnetic Suspension.—In the model G induction meter of the Stanley Instrument Company, U.S.A., the rotating system floats in air by means of a magnetic suspension, which is illustrated in Fig. 296.

The revolving parts consist of an aluminium disc and a soft steel vertical shaft, called the suspension core, to which the disc is secured, and which also carries the worm driving the dial train of the meter.

The suspension core is magnetically supported by the permanent magnet Y which is fitted with the steel plugs, or pole bushings, A and B. Above the pole bushing A is a compression spring, between which and the bottom stud screw is a fine steel wire. This wire passes through the magnet plugs, and also through the central hole of the suspension core. It is made taut by screwing up the stud screw, and so forms a perfect alignment. The suspension core is slipped over the wire, on which it floats, supported by the upward magnetic attraction between its ends and the magnetised plugs.

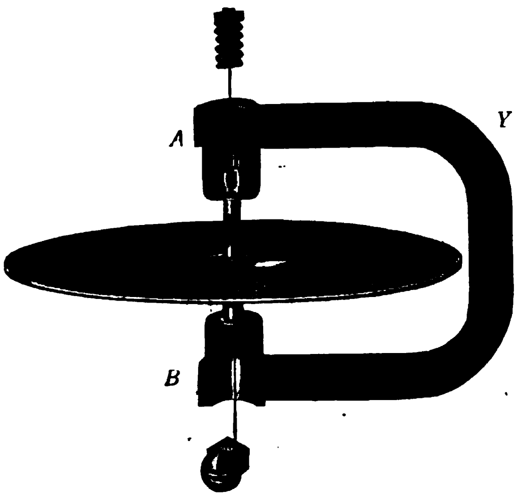

FIG. 296.

The lower end of the shaft is flanged larger than the body of the core, and, when the suspension magnet is not in place, the shaft will rest by gravity on the surface of the cup in the pole bushing B, but, due to a difference in the diameter of its flange and the cup, it does not touch the circumference of the cup at any point.

In this manner a definite air-space exists between the periphery of the flange and the circumference of the cup.

The upper end of the core is turned smaller in diameter than the body of the shaft; when under the influence of the magnet, this end is just inside the recess in the upper pole bushing A, otherwise it is just below the edge of this recess.

By means of the predetermined air-gaps surrounding the ends of the shaft, the magnetic fluxes at the top and bottom of the suspension core are localised, and the position of the shaft is perfectly defined under normal conditions. When the permanent magnet is placed in position, a field is established between it and the rotating shaft through the pole bushings A and B, and the whole revolving element is attracted upwards.

The flanged lower end of the suspension core is lifted out of contact with the cup in B, and the upper end is just carried within the recess in A.

The rotating element is thus held in a perfectly defined position in air, out of rubbing contact of any kind.

The advantage consists in the reduction of bearing surfaces and mechanical friction to a minimum ; also an exact alignment is obtained by the steel wire, and a central axis many times smaller than can be mechanically produced by pivots.

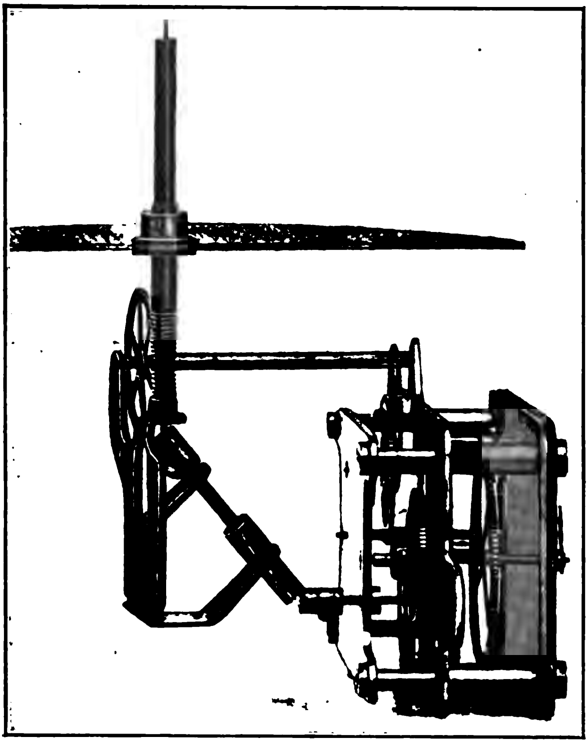

FIG. 297.

The accuracy of the meter is thus independent of the disturbing influence of friction.

Stanley Rotated Jewel Bearing.—This company also use a very novel jewel bearing in their latest type of jewel bearing induction meter. The jewel is mounted in a carrier shaft, which, in its turn, is geared through a bevel gear to the last wheel of the integrating train, so that, as the disc revolves and drives the train, it also causes the jewel, which is of circular form, to revolve beneath the pivot, presenting a constantly renewed surface to the end of the pivot. In addition, the pivot is supported against a specially designed coil spring. The gear reduction is such that 1000 kilowatt-hours must be registered before the jewel completes one revolution, or, in other words, before the pivot of the meter spindle makes contact

again with the same spot or point on the jewel surface, no matter how slight the movement of the train gearing. A view of the revolving element of the meter is given in Fig. 297, showing the connection between it and the integrating train, also the method of rotating the jewel bearing. The effect produced by this change of the point of contact with the pivot is to polish the surface of the jewel. The shaft supporting the jewel, which is cup-shaped, is at an angle of about 45 degrees to the vertical meter spindle. In consequence of this oblique position of the jewel under the pivot, the latter bears at the junction between the sides and the bottom of the cup, the junction being shaped to the proper curve.

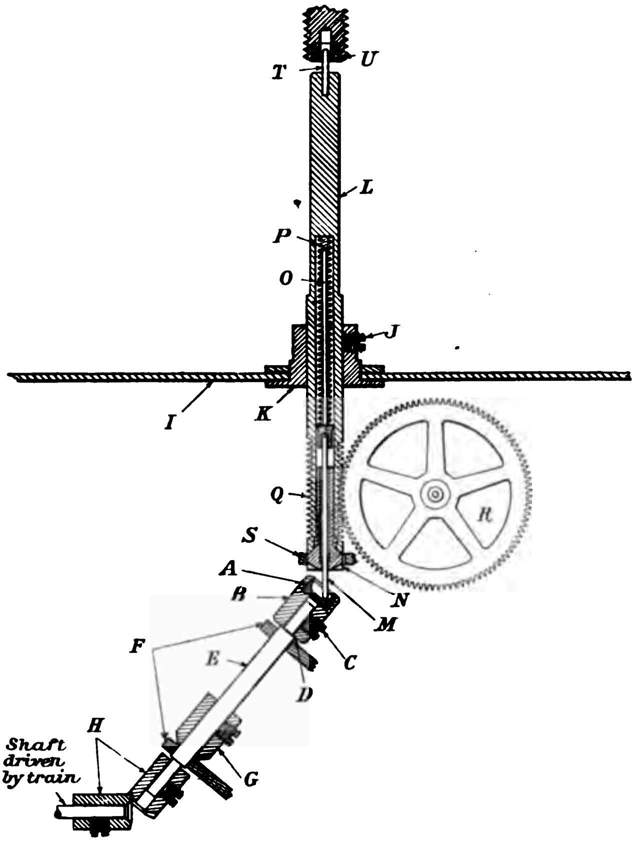

FIG. 298.

The construction of the rotated jewel bearing is given more in detail in the sectional drawing, Fig. 298, from which it will be readily followed. The disc I is carried on the meter spindle L, the revolutions of which are transferred through the worm Q to the wormwheel R actuating the integrating train. The lower pivot M runs in the jewel A, set in the jewel carrier B, which is secured to the revolving bearing shaft E by means of the set screw C. At H are the bevel gears through which the jewel bearing spindle

E is driven from the integrating train. Displacement of the meter shaft is prevented by the bracket S. The weight of the revolving element (disc and spindle) is supported by the spring P within the hollow meter axle, and no clamping device is required. The pivot M is removable by unscrewing N. The object of the pivot-stop O within the spring P is to prevent the disc spindle from descending far enough for the upper pivot T to come out of the guide-screw U.

Evershed Magnetic Suspension.—Mr Evershed, in his frictionless motor meter, also uses a magnetic suspension, the details of which are given in Fig. 299, which is a section through the magnetic pivot. The upper end S of the axle of the meter is held in position by the magnetic attraction of the iron rod R, which is screwed in the iron yoke Y, magnetised by the brake magnets M. The axle is prevented from being displaced by means of the guard ring *g*. The distance between R and the upper end of the axle can be adjusted until the upward magnetic attraction very nearly balances the whole weight of the armature, brake, and other parts attached to the meter spindle.

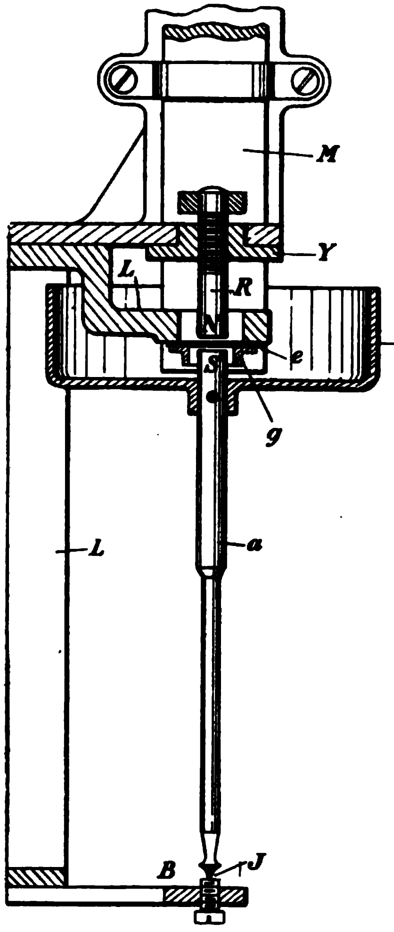

Fig. 299.

Upper Bearing.—The upper bearing, in general, presents no novel features, being mostly a guide bearing to keep the meter central. In the induction meter, type W, of the Fort Wayne Electric Works, U.S.A., the upper bearing is made flexible. The top end of the meter spindle is hollow, and rotates about a flexible steel shaft mounted in the top bearing screw. A small phosphor-bronze bearing collar encircles the point of the flexible steel shaft, so that friction is practically eliminated; and although the hollow end of the meter spindle permits lubrication, it is not found necessary. The lower end of the shaft is highly polished and hardened, and rests on a spring-seated jewel in the usual manner.

Integrating Mechanisms.—The integrating mechanisms used in meters are generally of two kinds, and consist of either the ordinary dial register with hands or pointers travelling over circles, or the cyclometer type of counter in which the figures either crawl or jump into position successively, and appear in slots in the face of the dial.

The first motion wheel of the integrating train is usually driven direct

from either a worm or pinion on the meter shaft. In the Ferranti continuous current meter the connection between the meter spindle and the dial frame is made through an intermediate swing train of wheels illustrated on page 39. The registering mechanisms used are clearly shown in the illustrations accompanying the descriptions of the various meters included in the preceding chapters.

To distinguish between the integral and decimal parts of the Board of Trade unit, the numbers denoting the decimals are generally coloured red.

Dial Register.—In the ordinary dial register the hands on the spindles of the different wheels rotate round circles, and no two adjacent hands revolve in the same direction; *i.e.* if the unit hand turn clockwise, the tens hand will go round in the counter-clockwise direction, and so on, the figures being marked round the dial circles in a corresponding manner. To facilitate the reading of the dials, so that the figures are always read in the same direction, clockwise, Messrs Mix & Genest, Berlin, supply a dial register in which every other hand is stationary, and the dial circle corresponding to the fixed hand rotates. The figures on each rotating dial circle always appear the right way up as they pass the fixed pointer. Messrs Hartmann & Braun, Frankfort, on the other hand, use a register with all the hands revolving in the same direction.

FIG. 300.

Cyclometer Counter.—A cyclometer counter has the great advantage over the ordinary dials with pointers, that an error cannot be made in taking the reading, as all the figures appear in one row, provided any two successive figures of the same number disc cannot show partially through the dial opening. Various constructions are used to prevent the numbers, owing to the very slow motions which take place in meters, from remaining in intermediate positions, whereby uncertainties are occasioned. The change from one number to the next higher one should be made suddenly by means of an intermittent motion of the number disc, so that it does not rotate continuously, as in the ordinary dial register and in the crawling type of cyclometer counter. Fig. 300 is an illustration of the jump cyclometer counter used by the Electrical Company, Limited, London.

Aron Spring Cyclometer Counter.—The counting train used in the Aron meters consists of a set of intermittently moving number discs which spring behind the openings in the dial, and not more than one figure can possibly show at a time through the aperture. The last of the discs, which is the first decimal place of the B.O.T. unit, revolves continuously, and the second and third places of decimals are given, for testing purposes, on small dials provided with moving pointers in the usual manner. These dials are, however, covered when the case is in position. The counter is shown in Fig. 301. B

is the continuously moving disc, and, as it rotates, it constantly winds up a small hairspring C. Each time the disc B completes one revolution and its zero figure comes in front of its dial opening, the hairspring is released and actuates the first springing disc A through a 1 to 10 cogged gearing. In this manner the consecutive numerals on the disc A are brought suddenly, one at a time, in front of the aperture, and each time a figure so appears the disc is locked until B has completed another revolution, when the same action takes place. The spring thus throws over the unit numeral 1 division, and is of sufficient strength to move, without sticking, all the dials, or as many of them as may be ready to move to the next higher figure. The different discs gear with one another by means of cogged wheels, as shown at W and W_1 (Fig. 301). Only at one point in the revolution of each disc does the cogged wheel gear into that of the next disc, so that the figures are locked in all intermediate positions. When the number 999 has been reached, each of the single teeth is ready to mesh with the cogwheel next to it, and as soon as the zero figure on the moving disc appears through the hole in the dial, the hairspring

FIG. 301.

swings all the discs together through one division, when they again become locked.

Siemens-Schuckert Weight Cyclometer Counter.—In the jump counters used in the Siemens-Schuckert meters the intermittent motion of the number discs is accomplished by means of a single weight rotating round the axis of one figure disc. The small amount of work required to lift the weight is independent of the number of figure discs to be moved at the same moment. The general arrangement is shown in the drawing in Fig. 302.

The motion of the armature spindle is transmitted by a worm on the axle to a wormwheel, connected to a counting mechanism fitted with rotating number discs. The first right-hand number disc is driven proportionally to the speed of the armature, while all the other discs move suddenly from one figure to the next. The worm *k* on the meter shaft is shown in the illustration driving direct the toothed wheel *a*, whereas, in general, the worm drives this toothed wheel through an intermediate wormwheel and pinion. On the axle of *a* is rigidly mounted the first number disc, which usually gives the first decimal place of the B.O.T. unit. The arm *g*, with the two pins *f* and *h*, is also rigidly connected to the axle of *a*, whereas the falling weight *b* and the transfer disc *c* are both loosely pivoted on it. As the

wheel *a* rotates, and with it the arm *g*, the pin *f* of the latter carries the weight *b* round with it, until it reaches the top position in which it is shown in the drawing. As *g* rotates further, the centre of gravity of the weight will come beyond the vertical line through the centre of rotation, and the weight will overbalance and fall to the bottom position. During its fall it carries round the transfer disc *c*, bringing the pin *i* into the position *i'*, whereby the toothed wheel *d* is moved through one tooth. The figure disc *e* is rigidly connected to the axle on which is mounted the toothed wheel *d*, and is, in this manner, turned through one-tenth of a revolution, the next number becoming visible in the dial aperture. By means of similar transfer discs, rigidly mounted on the following axles, as many number discs as are necessary can be used. It will be remembered that the first number disc rotates continuously, so that an error may occur if the reading be taken just at the

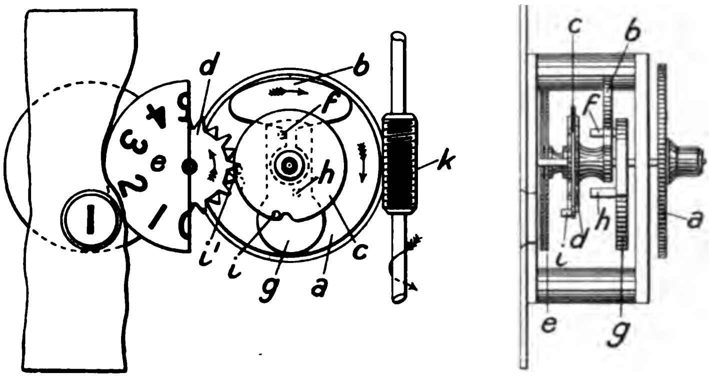

FIG. 302.

moment when the change is being made to the next higher numeral on the first intermittently moving number disc, which gives the unit figures. The reason is that the zero figure of the first decimal place always appears, due to the continuous rotation of its disc, just before the unit figure is changed, although the next higher unit figure appears very shortly afterwards. To eliminate any error due to this cause, an extra disc is used, rigidly attached to the first transfer disc and weight. The unit figure disc, which is connected to the axle of the wheel *a*, has marked on it the figures 1 to 8, which, therefore, revolve continuously, the portion of the disc being cut away where the figures 9 and 0 should be. These figures, 9 and 0, are marked on the extra number disc, and are arranged diametrically opposite one another, and in each half of their revolutions they move suddenly, due to the weight. The two discs are placed behind one another, and their figures appear in succession opposite the same dial opening, the 9 and the 0 moving in turn suddenly into position. In this manner the zero figure of the first decimal place and the next higher unit figure can only appear simultaneously.

CHAPTER XIV.

METER TESTING.

General Remarks—Meaning of Testing Constant—Calculation of Percentage Error—Testing Motor Meters—Testing Oscillating, Clock, and Electrolytic Meters—Determination of the Losses in a Meter—Testing Meters *in situ*—Portable Meters for Testing.

General Remarks.—All measuring instruments require to be calibrated, adjusted, and tested by comparison with standards of reference to ensure their proper working, and to no class of electrical apparatus does this apply more forcibly than to electricity meters, on the accuracy and reliability of which depends the revenue of the supply station.

A comprehensive treatise on meter testing would require a volume to itself, and should not only give the methods of testing meters of different types, but also actual tests carried out under different conditions with a full explanation of the results, descriptions of the standard testing instruments employed and their limitations, the proper equipment of a meter testing department, and descriptions of some typical testing institutions. This is quite beyond the scope of the present work, and in this chapter it is only intended to give a brief outline of the testing of meters after they have been adjusted and calibrated at the factory.

The calibration of a meter is the operation by means of which the measurements effected by it are compared with the simultaneous measurements of standard testing instruments, the character of which depends on the nature of the particular type of meter. The adjustments of a meter are the alterations which have to be made to the different elements of the meter in order to adapt it to the circuit for which it is intended, and to bring it into accord with the current or watt measurements, as given by the standard testing instruments. The testing of a meter is the checking of the same after it has left the meter factory, in order to ascertain whether it has been accurately adjusted and calibrated, and is in proper condition, fit for installation in a consumer's premises. A meter should also be periodically and systematically tested *in situ*, to determine whether it is working correctly under the conditions which prevail in actual practice, and to detect any irregularities or faults which may have arisen during its use.

In the meter factory the component parts of a meter are subjected to a series of both mechanical and electrical tests and close inspection during each step of manufacture, when the parts have been assembled, and finally in the testing department, where the finished instrument is accurately adjusted and calibrated. It should not be necessary, once the meter cover has been put on and sealed, for such adjustments to be changed. If, when subsequently tested, the meter should be found to be incorrect, the adjust-

ments should be altered by the manufacturer only; in fact, all adjustments should be sealed.

In a motor meter the jewels and pivots have to be microscopically examined, as well as the wheels and pinions of the registering train, and the worm on the spindle; the exact strength of the spring supporting the jewel in the jewel screw must be carefully gauged, that it is of the correct value in relation to the weight of the moving part, which should be accurately balanced and centred. All contacts, especially those to the commutator, if any, and the state of the commutator, have to be examined, and the correct pressure of the brushes on the commutator has to be regulated. Particular care must be given to the manufacture of the permanent magnets, so that they will withstand temperature variations and vibration, and still retain their original magnetic strength for extensive periods. When the magnet has been made, it is tested either by the ballistic galvanometer or the magnetometer methods, and is stored for several months. Before its actual inclusion in a meter it is re-tested, and if it should not exactly measure as originally it is discarded. The different circuits of the meter have to be tested for conductivity and insulation, and are subjected to pressures greatly in excess of the normal voltage of the supply circuit. In general, the meter department of a manufacturing company is well supplied with modern and accurate standardising instruments. The actual methods and arrangements adopted vary in detail to suit the particular requirements of the factory for quickly and accurately testing and adjusting large quantities of meters on a commercial basis.

Every supply station should have a meter department equipped with a full complement of accurate testing instruments, testing racks free from vibration, incandescent lamps and adjustable resistances, which can be suitably arranged for keeping any particular load constant, and will at the same time give a wide range of load, and choking coils for inductive loads. The testing circuits should be fed with current from an independent source, and not with current from the supply mains. For testing energy meters two distinct and independent testing circuits should be used, the one for the pressure circuits and the other for the main current circuits of the meters. Whenever possible, this method should be adopted both for direct current and alternating current energy meters. Only the best standard instruments should be used. It must be remembered that a high degree of accuracy is demanded of a meter, in some cases unnecessarily high; and tests become quite valueless when carried out with inferior instruments, with want of care, and unless the voltage and current are both kept constant; above everything, a test should be accurate and reliable.

The necessary instruments are ammeters, voltmeters, wattmeters, and accurate stop-watches. A potentiometer is a highly accurate and useful instrument for measuring both currents and pressures, and is largely used in many supply stations and testing laboratories, and Kelvin ampere and watt balances are also employed for accurate work. Special care should be given to the selection of a reliable and accurate stop-watch, as the average stop-watch is not always correct at all points of its dial. It should be frequently checked when in use, and examined for any zero error. The hand should return to zero without springing back into position. The moment the key is pressed the hand should be released and start to indicate the time, with the second depression it should be immediately arrested, and on pressing a third time it should move at the ordinary rate to the zero position, on arriving at which it should stop. Testing sets for insulation and ordinary resistance

measurements are also necessary and low reading voltmeters. Ammeters and wattmeters of different ranges should be employed, the actual number and range of each depending upon the capacities of the meters to be dealt with.

A meter has to be tested over a wide range, from one-twentieth or one-tenth of full load to the maximum load capacity of the circuit for which it is intended, and it is of the greatest importance that the current or watt measurements, or both, should be equally accurate and reliable at every test load. This is not possible with a single instrument, admitting at the same time of a wide range; and a small error in a reading at a low load introduces a considerably larger percentage error than the same actual error at a high load.

The various tests which should be made on a meter, with special reference to the motor type, are—speed tests for accuracy at different loads; a time test; the determination of the losses in the meter, *i.e.* the loss in the main circuit and that in the shunt circuit; the effect of varying the pressure; the effect of varying the frequency (if an alternating current meter); the effect of temperature changes; the effect of stray fields, a test for creeping, and the effect of a short-circuit current passed through the meter. Were it not for the disturbing influence of friction, especially at light loads, it would only be necessary to conduct one test at full load. As, however, the law of the motor meter is not a straight line law, it becomes necessary to test it at different points throughout its range, and the low load tests are, perhaps, more important than those at full load and above, as generally a meter is working in service very much below its rated capacity. The speed tests consist in checking the speed of the meter disc or spindle at different loads, usually between one-tenth and full load, and for this purpose the 'testing constant' of the meter has to be used. Practically, a speed test is the determination of the percentage difference of the testing constant from its declared value. The time test is, in general, undertaken with the object of ascertaining the condition of the registering gear and train, and consists in sending a suitable current through the meter, and maintaining it constant for some time, comparing the actual units consumed in the particular interval with the units registered by the meter. It gives a general idea of the behaviour of the meter. It can be readily carried out by comparing the registration of the meter under test with the units given by a standard meter, when it is unnecessary to keep the load constant.

Meaning of Testing Constant.—The testing constant of a motor meter is the relation which exists between the correct speed of the meter armature and the load. It does not in any way refer to the meter dials, which generally give the units consumed without the use of a multiplier or constant.

As this testing constant is variously expressed by different meter makers, it is most essential to understand exactly what it represents in each case. In ampere-hour motor meters the testing constant connects the speed of the armature, or disc, with the current. It may be expressed as the number of amperes per revolution per second, the number of ampere-seconds per revolution, or the number of revolutions per second per ampere. Instead of using the second as the unit of time, in some cases the minute or the hour is chosen, and this also modifies the meaning of the testing constant. In energy motor meters the testing constant connects the speed with the power in watts. A very general way of expressing it is, that it represents the number of watts per revolution per second. In certain energy motor meters the testing constant is the number of revolutions per minute per 1000 watts, in others it

means the watts per revolution per 100 seconds, the revolutions per watt-hour, also the watt-seconds per revolution. It may further mean the number of watts per revolution per hour or per minute.

Difficulties would be avoided if the testing constant of a meter had a precise and universally-accepted definition assigned to it. Its actual value would depend, as it does at present, on each meter, but it would always have the same meaning for the same type of meter (quantity or energy), and only one form of the corresponding testing formula would be required. The formula required in testing an energy motor meter is easily deduced in the following manner:—

N = any convenient number of revolutions of the meter disc.
T = the *correct* time in seconds required for this number of revolutions.
T′ = the *observed* time in seconds taken by the disc in executing N rotations.
C = current in amperes.
V = pressure in volts.
W = actual load in true watts.
K = testing constant of meter.

(A.) K denotes the number of watts per revolution per second.

When the meter is correct, then

$$K = \frac{W \times T}{N}.$$

Proof:—

$$1 \text{ revolution per second} = K \text{ watts.}$$

$$\therefore \qquad N \text{ revolutions in T seconds} = \frac{N}{T} K \text{ watts.}$$

This must be equal to the watts W measured by the wattmeter, when the meter is correct,

$$\therefore \qquad W = \frac{N}{T} K;$$

$$\textit{i.e.} \qquad K = W \cdot \frac{T}{N}.$$

$$\text{or} \qquad (1)\ \text{Testing Constant} = \frac{\text{Watts} \times \text{Seconds}}{\text{Revolutions}}.$$

The above may be variously expressed as follows:—

$$(2)\ \text{Watts} = \frac{\text{Testing Constant} \times \text{Revolutions}}{\text{Seconds}}.$$

$$(3)\ \text{Revolutions} = \frac{\text{Seconds} \times \text{Watts}}{\text{Testing Constant}}.$$

$$(4)\ \text{Seconds} = \frac{\text{Revolutions} \times \text{Testing Constant}}{\text{Watts}}.$$

(B.) If K be expressed in watts per revolution per minute, then

$$K = \frac{W \times T}{60N}.$$

(C.) If the constant represent the watts per revolution per hour, then

$$K = \frac{W \times T}{3600 \times N}.$$

(D.) When K denotes the revolutions per minute per 1000 watts, then

$$K = \frac{60 \times 1000 \times N}{W \times T}.$$

From the above examples no difficulty will be experienced in obtaining the correct formula to correspond with any particular testing constant. With ampere-hour motor meters the current C amperes must be substituted for the watts W. In a direct current system the power in watts (W) equals the product of the current and voltage (C.V); in an alternating current system, however, the power W includes the power factor of the circuit, *i.e.* $W = C.V. \cos \phi$.

Calculation of Percentage Error.—The actual error at any load is $T - T'$, and the percentage error is $\frac{T - T'}{T} \times 100$. When this expression is positive the meter is fast, and is slow when it becomes negative. The correct time T is computed from the formula, and T′ is the observed time. The percentage error can be determined in a number of ways; it may be calculated from the standard, measured watts and the watts as given by the meter, using the declared value of the testing constant and the observed values of the revolutions and the time, from the observed revolutions per minute of the meter disc and the calculated number of revolutions per minute, or from the declared value of the testing constant and from its value deduced from the formula, using the observed values of the watts, time and revolutions. If the percentage error be estimated from the watts, then, assuming K to represent the number of watts per revolution per second, the meter will from its speed indicate $\frac{K.N}{T'}$ watts, whereas the wattmeter reading is W watts. The actual error is $\frac{K.N}{T'} - W$, and the percentage error is $\dfrac{\frac{K.N}{T'} - W}{\frac{K.N}{T'}} \times 100$. If this expression be negative, it means that the meter is reading low, and it will be reading high when the expression is positive.

From the percentage error table for fifths of a second given below, the percentage error may be readily obtained without having to work it out. The table is based upon one supplied by the Duncan Electric Mfg. Co., U.S.A., and can be used directly without any special interpretation. This is not the case with the American table, as it is calculated from the formula $\frac{T - T'}{T'} \times 100$, which is *not* the one accepted here. The method of using the table is very simple. It is only necessary to adjust the load on the meter until the revolutions, supposing the meter to be correct, will require exactly one minute to be completed. The number of revolutions

20

Per Cent. Error Table for Fifths of a Second.

Time in Seconds.	Per Cent. Fast.	Time in Seconds.	Per Cent. Fast.	Time in Seconds.	Per Cent. Slow.	Time in Seconds.	Per Cent. Slow.
40·20	33·00	50·20	16·33	60·20	0·33	70·20	17·00
·40	32·67	·40	16·00	·40	0·67	·40	17·33
·60	32·33	·60	15·67	·60	1·00	·60	17·67
·80	32·00	·80	15·33	·80	1·33	·80	18·00
41·00	31·67	51·00	15·00	61·00	1·67	71·00	18·33
·20	31·33	·20	14·67	·20	2·00	·20	18·67
·40	31·00	·40	14·33	·40	2·33	·40	19·00
·60	30·67	·60	14·00	·60	2·67	·60	19·33
·80	30·33	·80	13·67	·80	3·00	·80	19·67
42·00	30 00	52·00	13·33	62·00	3·33	72·00	20·00
·20	29·67	·20	13·00	·20	3·67	·20	20·33
·40	29·33	·40	12·67	·40	4·00	·40	20·67
·60	29·00	·60	12·33	·60	4·33	·60	21·00
·80	28·67	·80	12·00	·80	4·67	·80	21·33
43·00	28·33	53·00	11·67	63·00	5·00	73·00	21·67
·20	28·00	·20	11·33	·20	5·33	·20	22·00
·40	27·67	·40	11·00	·40	5·67	·40	22·33
·60	27·33	·60	10·67	·60	6·00	·60	22·17
·80	27·00	·80	10·33	·80	6·33	·80	23·00
44·00	26·67	54·00	10·00	64·00	6·67	74·00	23·33
·20	26·33	·20	9·67	·20	7·00	·20	23·67
·40	26·00	·40	9·33	·40	7·33	·40	24·00
·60	25·67	·60	9·00	·60	7·67	·60	24·33
·80	25·33	·80	8·67	·80	8·00	·80	24·67
45·00	25·00	55·00	8·33	65·00	8·33	75·00	25·00
·20	24·67	·20	8·00	·20	8·67	·20	25·33
·40	24·33	·40	7·67	·40	9·00	·40	25 67
·60	24·00	·60	7·33	·60	9·33	·60	26·00
·80	23·67	·80	7·00	·80	9·67	·80	26·33
46·00	23·33	56·00	6·67	66·00	10·00	76·00	26·67
·20	23·00	·20	6·33	·20	10·33	·20	27·00
·40	22·67	·40	6·00	·40	10·67	·40	27·33
·60	22·33	·60	5·67	·60	11·00	·60	27·67
·80	22·00	·80	5·33	·80	11·33	·80	28·00
47·00	21·67	57·00	5·00	67·00	11·67	77·00	28·33
·20	21·33	·20	4·67	·20	12·00	·20	28·67
·40	21·00	·40	4·33	·40	12·33	·40	29·00
·60	20·67	·60	4·00	·60	12·67	·60	29·33
·80	20·33	·80	3·67	·80	13·00	·80	29·67
48·00	20·00	58·00	3·33	68·00	13·33	78·00	30·00
·20	19·67	·20	3·00	·20	13·67	·20	30·33
·40	19·33	·40	2·67	·40	14·00	·40	30·67
·60	19·00	·60	2·33	·60	14·33	·60	31·00
·80	18·67	·80	2·00	·80	14·67	·80	31·33
49·00	18·33	59·00	1·67	69·00	15·00	79·00	31·67
·20	18·00	·20	1·33	·20	15·33	·20	32·00
·40	17·67	·40	1·00	·40	15·67	·40	32·33
·60	17·33	·60	0·67	·60	16·00	·60	32·67
·80	17·00	·80	0·33	·80	16·33	·80	33·00
50·00	16·67	60·00	0·00	70·00	16·67	80·00	33·33

per minute at the particular load is calculated from the testing formula. In the case of a Duncan meter the formula is

$$\frac{W}{K \times 60} = \text{Revs. per min.}$$

The reason for the number 60 in the denominator is because the constant of the Duncan meter is the number of watts per revolution per hour. If the testing load be 6000 watts, and the meter be of 100 amperes capacity and 110 volts pressure, the number of revolutions per minute should be

$$\frac{6000}{K \times 60} = \frac{6000}{4 \times 60} = 25.$$

(K in this case is 4.)

The tester notes the exact time in seconds required for the 25 revolutions to be executed by the meter disc at the load of 6000 watts, and then refers to the table. If the time be exactly 60 seconds, the meter will have no error; if, however, it be 58·4 seconds, the meter is 2·67% fast, as per table. If it should take 55·8 seconds to make the 25 revolutions, it would be 7·00% fast; again, if the time were more than 60 seconds, say 61·8 seconds, the error would be 3·00% slow.

Testing Motor Meters.—In carrying out a speed test on a motor meter the revolutions are accurately counted by noting the appearance or disappearance of the mark on the meter disc through the observation window in the meter cover. In slow rotations an error may be made at the moment of stopping the stop-watch at the termination of the test, owing to the mark on the periphery of the disc being, in general, a fairly large spot, so that the completion of the last rotation is not always noted in the correct position. In other words, unless care be taken, the watch may be stopped too soon or too late. The observation window should have engraved on it at its centre a small line parallel to the meter axis, and a corresponding line should be made on the coloured portion of the rim of the disc. This should make the observations more definite. If the meter be an ampere-hour meter, it is connected to the testing circuit in series with an accurate ammeter; or a potentiometer, or Kelvin ampere balance is used. The meter must be supported in the vertical position, and the locking device, if any, must be released before current is passed through the meter. The load is then adjusted to the correct value and is kept constant, and the speed observations are taken. This, of course, applies to any meter. In testing a three-wire ampere-hour motor meter, such as the three-wire O'K. meter described on page 45, the two armature circuits are either connected in series and tested, or each armature circuit is tested separately at different loads. The pressure of the circuit need not be taken into account in conducting a speed test of an ampere-hour motor meter, except when the testing dials of the meter are used.

In many meters the speed of rotation is too high at full load to be determined by counting the rotations, and the testing dials are then read at the commencement and termination of the test. The testing dials are generally calibrated to read the decimal portions of the Board of Trade unit; the testing constant is then not required, but the value of the voltage of the meter must be used in computing the watt-hours, or B.O.T. units, from the ammeter reading and the time. When the testing dials are used the duration of the test should be so chosen that complete revolutions are made, as otherwise errors may creep in, due to discrepancies in the dial graduations. These

testing dials are differently coloured from the remainder, and are only used in checking the meter. For the same purpose the decimal portions of a cyclometer counter are also differently coloured. In a time test on an ampere-hour meter, the voltage must also be taken into account in estimating the units consumed.

When an energy meter is to be tested, a wattmeter, an ammeter, and a voltmeter must be used. The connections of the different instruments to the testing circuits must be made in such a manner that the shunt loss of the meter is not indicated by the testing instruments, and that the pressure currents of the voltmeter and wattmeter do not pass through the series circuit of the meter, otherwise incorrect results will be obtained. The best method is to have two independent two-wire circuits,—a main current one for the load in which are placed the series circuits of the meters and the main current coils of the wattmeter and ammeter, and a potential circuit, across which are connected in parallel the pressure circuits of the meters, wattmeter and voltmeter. Even when two independent testing circuits are not available, a pair of potential leads should be branched from the main circuits on the *supply side* of the meters and testing instruments, and the voltmeter and the pressure circuits of the meters and wattmeters should be connected to these leads.

The energy motor meter is tested by either counting the revolutions of the disc and observing the time taken, or the testing dials are read. Simultaneous readings of the wattmeter, ammeter, and voltmeter are taken, and during each test the current and voltage must be maintained perfectly constant. When the meter is for a direct current system the wattmeter is not essential, but is indispensable in the case of alternating current meters, and the ammeter and voltmeter must be used to determine the power factor, if any. In ascertaining the accuracy at different loads, in general, two ammeters and two wattmeters are necessary, and arrangements are made to short-circuit the terminals of the low-reading ammeter and wattmeter at the high loads. If the ammeter be of the moving coil type, it is provided with different shunts to give the desired ranges, so that only one instrument is used. A three-wire energy motor meter, such as the Thomson type, may be tested by connecting both its main current coils in series and checking it as an ordinary two-wire meter, the armature circuit being energised at the proper voltage. It is also checked by testing each half of the meter as a two-wire meter at different loads, and the results obtained for the two halves should not differ appreciably from one another. The effect of the series coils on the armature may be tried by so connecting them that, with the same current, their magnetic fields oppose one another, when the armature should remain stationary. The armature must be connected to the potential leads during the test. This method is not satisfactory, from the fact that the armature does not rotate, and the effect of friction cannot, therefore, be observed. A three-wire energy meter should be tested on a three-wire circuit. Two wattmeters are then employed, the one being placed in the one half of the system and the second in the other half. The three-wire network should then be balanced and the meter tested, and the tests repeated with the two sides unequally loaded.

When an alternating current meter is being tested, its accuracy must be determined not only on different loads with a power factor of unity, but also when the power factor is less than unity, say 0·7 and 0·5. It is also necessary to keep the frequency constant, and some form of suitable frequency

indicator should be used. Induction meters are affected by variations in periodicity, and the frequency should be accurately known. It may be easily determined by taking the revolutions of the alternator with an ordinary speed counter, and is calculated from the following formula:—

$$\text{Cycles per second} = \frac{\text{Revs. per minute} \times \text{No. of poles}}{120}.$$

A very general method of testing a polyphase motor meter is to check each half of the meter in the same manner as a single-phase two-wire induction meter. Both the pressure circuits of the meter are placed across the testing mains, but current is only sent through one main current coil at a time. A series of tests is made with this current coil in circuit; it is then entirely disconnected, and the current is passed through the other main circuit of the meter, when the tests are repeated. The usual standard indicating instruments are used. It is most important, in using this method, that both the pressure circuits are always energised during the test, whichever half of the meter is under examination. If this precaution be overlooked, the results will be incorrect, owing to the braking action of the shunt flux of the unloaded half of the meter; the determinations would all be too high. The speed of the meter disc will, with this method, be half the speed when both sides are loaded, *i.e.* with the meter connected to a polyphase system, and this fact must be taken into account in using the testing constant. Checking each half of the meter in this manner has the advantage of indicating the state of balance of the two driving torques of the meter; they should be almost exactly equal. When the meter has been properly adjusted and calibrated, it should only be necessary for such tests to be quickly conducted at a couple of loads, when the meter should be checked as a polyphase meter in a polyphase circuit. For this purpose, taking a three-phase three-wire meter, it should be connected to a three-phase three-wire network, when two wattmeters must be used. The wattmeters are joined to the system on the two-wattmeter method of connection, and the sum of their simultaneous readings gives the total three-phase power. Three ammeters and three voltmeters should also be employed. The meter should then be checked at different loads, both with the system balanced and unbalanced, first with loads of unity power factor, and then with loads containing either self-induction or capacity. In the case of a three-phase four-wire meter, three wattmeters must be employed in order to obtain the true three-phase power. The main current coils of the wattmeters are placed in the three supply mains, and the pressure circuit of each wattmeter is connected between that supply main in which its main current coil is inserted and the fourth or neutral conductor. The method of connection is exactly the same as that shown in Fig. 184 on page 188 to illustrate the measurement of the energy consumed in a three-phase four-wire system by means of three induction meters. In every case when an energy meter is being tested, care must be exercised that no pressure current passes through the main current circuits of the meter (or meters) and those of the indicating instruments. This is specially important when a number of meters are tested in series, and the pressure circuits should then always be completely isolated from the main current terminals of the meters and connected in parallel across the testing circuit. The arrangement of the terminals should admit of this without the necessity of disturbing the main meter cover. When an alternating current meter is to be used with a special current or pressure transformer or two such transformers, it should be tested, connected to the

transformer, or transformers, as for ordinary use, especially for inductive loads.

Explanations of the adjustments of motor meters, especially those of the induction type, will be found in the descriptions of the different meters given in the foregoing chapters. The principal adjustment is that of the permanent magnets to control the speed of the meter at heavy loads, where the effect of any slight discrepancy at light loads is not very appreciable. The other important adjustment is the regulation of the light-load or friction-compensating device for varying the speed on small loads. In addition, an induction meter has to be provided with a phase adjustment, so that its indications will be correct on loads having the usual power factors met with in practice. This also applies to each half of the polyphase meter.

The effect on the indications of a meter of an increase or decrease in the voltage is readily determined by testing the accuracy at one and the same load with pressures applied to the testing mains, differing by 10 per cent. above and below the normal. Similar tests have to be taken for differences in frequency and temperature. Creeping is determined by energising the shunt circuit of the meter, with the main circuit open, on a voltage 10 to 20 per cent. in excess of the normal; the meter disc should remain stationary. In testing a meter it should be in a position remote from magnets, bus-bars, or heavy current cables, the magnetic fields of which may influence its accuracy. It might be advisable to test a switchboard, astatic meter, such as the Thomson type, in the vicinity of such magnetic fields, as it is impossible, for mechanical reasons, for the meter to be absolutely independent of the magnetic fields emanating from bus-bars, feeders, and heavy current connections, which, as a rule, do not occupy a symmetrical position relatively to the two armatures of the meter. The weakening effect on the permanent magnets of an abnormal current through the main circuit of the meter is examined by subjecting the meter to a short-circuit through a fuse of double the capacity of the meter, and afterwards taking speed tests at full load.

Testing Oscillating, Clock, and Electrolytic Meters.—An oscillating meter, such as the Electrical Company's type described in Chapter V., is tested in the same manner as a motor meter. In counting the oscillations of the meter disc, care must be taken to include whole oscillations only. A complete oscillation corresponds to one rotation in a motor meter, and is the passage of the meter disc twice in succession in the same direction through a given position. In the testing formula, N now means the number of oscillations, and K connects the rate of oscillation with the power in watts. The method of checking an Aron clock meter is to take a time test, usually at full load only, as the law of the meter is a straight line law. The duration of each test should be an exact multiple of twenty minutes, as in this way errors due to want of synchronism are eliminated. The test for the creeping error of the Aron meter can only be taken by energising its pressure circuit, without load on the meter, for a week or longer, and noting the readings of the dials every day A non-creeping device is now attached to these meters. It consists of a small coil in the pressure circuit of the meter, and is placed so that it acts on one pendulum coil only, tending to drive the meter backwards. This backward movement is, however, prevented on no load by a pawl attachment to the register.

In electrolytic meters, such as the Wright shunted type and the Bastian un-shunted meter, time tests have also to be taken. The meter is placed in the circuit, the current, usually a full load current, is maintained steady, and

the scale readings are carefully read during the test. In the Wright meter the temperature coefficient of the circuit comprising the fine wire resistance and the electrolytic cell should be tested for any change for a range of 10 degrees Centigrade above or below the normal. Either a full load test is conducted at a temperature differing by this amount from the normal, or the resistance of the cell circuit is measured by a potentiometer at the normal temperature and at a higher one. In a properly adjusted meter, no difference will be found. The accuracy of the point at which the mercury syphons over in those meters fitted with the secondary 100-unit scale is examined by shaking over mercury until the mercury column stands at 97 or 98 on the unit scale; a current is then passed through the instrument until the mercury flows over. The syphoning point should occur at the 100th division. The calibration of the Bastian meter may be quickly checked without passing current through the meter. Water is poured into the tube up to the lowest scale division with the electrodes inserted, when, by means of a burette, quantities of water are added equivalent to 10 or 20 units at the voltage for which the meter is calibrated, and the different levels noted. They should coincide with the corresponding scale divisions.

Determination of the Losses in a Meter.—Power is wasted in both the series and pressure circuits of an energy meter, but of the two losses the shunt loss is the more important. In a direct current meter the loss in the main current circuit is determined by measuring the drop at full load between the main current terminals of the meter with an accurate low-reading voltmeter, or a potentiometer may be used, and multiplying the drop in volts by the current in amperes. In general, it is only necessary to ascertain the drop. The shunt loss is found by measuring the resistance in ohms of the pressure circuit, when the quotient of the square of the normal working voltage of the meter by the resistance will be the watts lost in the shunt at this pressure. Before a measurement of the resistance is taken, the normal working voltage should be applied to the shunt circuit of the meter for quite an hour, with the meter cover on during this time. In fact, all measurements should be made without disturbing the cover of the meter. In many meters the removal of the cover will make a perceptible difference to the meter speed at full load. The shunt loss may also be determined by measuring the current in the pressure circuit. The product of the pressure and the current is the power wasted. The former method is, however, the simpler and better of the two.

The above methods for obtaining the series and shunt losses are not applicable to a meter of the induction type, on account of the self-induction of its circuits. The shunt loss may be measured by means of an accurate low-reading wattmeter. The wattmeter is placed in the alternating current mains with the meter under test, but in front of the same, so that the only load on the testing mains is that due to the pressure circuit of the meter and is indicated by the wattmeter, care being taken that the pressure current of the wattmeter does not pass through its series coil. An approximate result may be obtained by connecting a number of meters of the same ampere capacity, voltage, and frequency to the circuit in this manner, the pressure circuits of the meters being all in parallel across the mains, and constituting the load. The aggregate watts lost in the shunts of the meters will be given by the wattmeter reading; dividing this number of watts by the number of meters tested will give an approximate average value of the shunt loss per meter. The only advantage of the method is that a wattmeter of larger

capacity can be used. An accurate determination of the shunt loss may be carried out by employing the three-voltmeter method of measuring power in an alternating current circuit containing self-induction. For this purpose three voltmeters and a non-inductive resistance are necessary. The non-inductive resistance is connected in series with the shunt circuit of the meter, and an alternating current pressure is applied to the terminals of the circuit so formed. The one voltmeter is connected direct across the circuit, the other is joined to the shunt terminals of the meter, and the third is placed across the non-inductive resistance. The total voltage applied and the non-inductive resistance must be so regulated that the pressure across the shunt of the meter is the normal working voltage for which it is intended. The watts dissipated in the shunt at this pressure are given by the following equation :—

$$W = \frac{1}{2r}(V^2 - V_1^2 - V_2^2),$$

where r is the known value in ohms of the non-inductive resistance, V, V_1, and V_2 being the voltages given by the three voltmeters, taken in order across the total circuit, the shunt of the meter, and the non-inductive resistance. The advantage of the method is that it is totally independent of self-induction, but it has the disadvantage that, to render it sensitive, the volts V_2 lost in the non-inductive resistance should be comparable with V_1. The power wasted in a circuit containing self-induction may be measured by the three-ammeter method. The circuit under test in series with an ammeter is shunted by a non-inductive resistance also in series with a second ammeter. The parallel circuit so formed is placed in one of the testing mains, in which is inserted a third ammeter, so that the currents in the branch circuits flow through it, three simultaneous readings of the ammeters are taken, and the power wasted is calculated from the formula

$$W = \frac{R}{2}(A^2 - A_1^2 - A_2^2),$$

where R is the resistance of the non-inductive shunt, A is the current in amperes by the ammeter in the main circuit, A_1 is the current in amperes by the ammeter in the circuit having self-induction, and A_2 is the ammeter reading of the current in the non-inductive shunt. The above two methods of measuring power in an alternating current circuit have the disadvantage, in common, that a small error in either the ammeter or voltmeter readings introduces a large error into the result, which depends on the squares of the readings. The drop in the series circuit of the induction meter is measured by means of a low-reading voltmeter suitable for measuring alternating current pressures.

Testing Meters *in situ*.—A meter may give satisfactory results when checked at the station, and yet may develop serious faults after some months of continued use under the conditions which obtain in practice. It is, therefore, not only desirable but important to systematically test the accuracy of a meter while in circuit. Such periodical tests show at once the condition of a meter, and are the only means by which faults can be detected. For testing meters *in situ* a stop-watch, a portable testing instrument, and a testing load are required. The testing load usually consists of resistances, or a number of lamps, arranged in a portable case provided with quick-break switches for varying the load. The testing instrument may be either

a portable standard wattmeter, or a testing set consisting of a combined voltmeter and ammeter of the moving coil type, having various ranges. For an alternating current circuit the wattmeter should invariably be used.

The test may be conducted in one of two ways: either the consumer's lamps may be used for the load, when the testing instruments must be placed in the installation, or a separate circuit must be branched off the supply mains and the meter placed in it together with the artificial load and wattmeter, or ammeter and voltmeter. This latter method should always be employed, as it is independent of the consumer's load. With either method it is necessary to interrupt the consumer's circuit at the start and finish of the test, unless special connections, called test terminals, have been

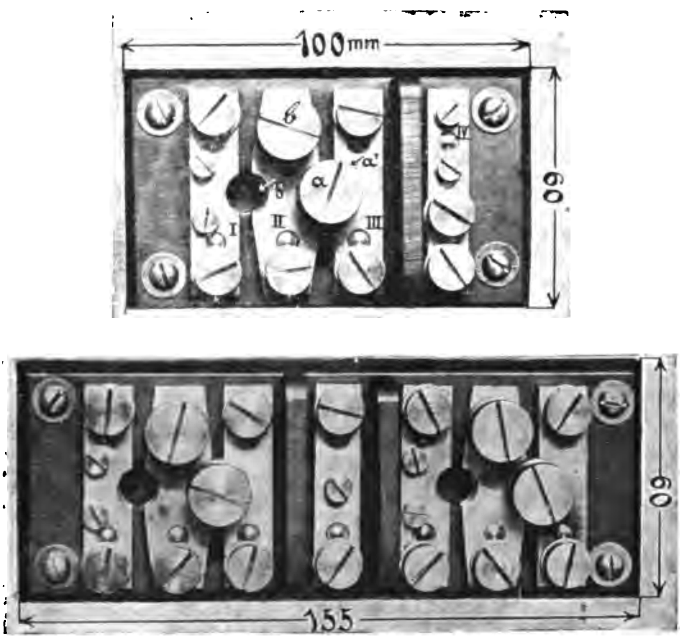

FIG. 303.

installed with the meter. These connections consist of terminals with short-circuiting bars or plugs, and they are either mounted in a separate and portable form on a slate or marble base, or are permanently attached to the meter. By their aid the operations incident to changing the meter from one circuit to the other and re-inserting it in the installation, or replacing it by a new meter, may be rapidly and easily performed without any interruption to the consumer's circuit. These testing connections are largely used on the Continent, and are made by many Continental manufacturers, differing only in form, arrangement, and the number of interconnections which have to be made. The test terminals of the Deutsch-Russische Elektricitätszähler-Gesellschaft, Germany, are of very simple form, and may be regarded as typical of this class of meter accessory; they also have the advantage that

only one screw plug need be manipulated in short-circuiting the meter, or in opening and closing a current circuit. The general appearance of the test terminals made by this company will be gathered from the illustrations in Fig. 303, of which the upper set is for a two-wire circuit, and the lower one represents the arrangement for a three-wire network. Referring to the two-wire test terminals in Fig. 303, the ends of the main current circuit of the

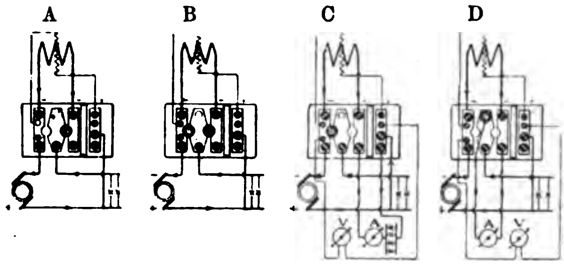

FIG. 304.

meter are brought to the terminals I and III at the top, and the terminals I and II are connected by the bottom screws to one of the supply mains. The shunt terminal of the meter is connected to the terminal IV, which is joined to the other supply main. In this position, with the screw plug *a* inserted in its hole *a′* between the terminals II and III, the meter is connected to the installa-

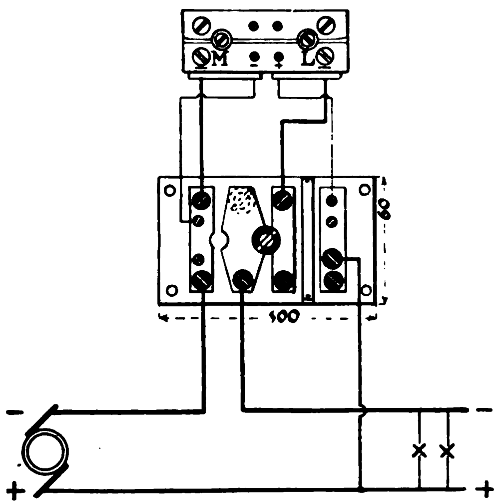

FIG. 305.

tion for everyday use, as shown diagrammatically at A in Fig. 304. When the meter is to be tested on the artificial load, the screw plug *b*, Fig. 303, is first placed in the hole *b′* between the terminals I and II, as illustrated by the diagram at B in Fig. 304. The meter is now short-circuited, and can, if necessary, be entirely disconnected and a new one inserted in its place. The screw plug *a*, Fig. 303, is then removed from the hole *a′*, and the meter is ready for testing on the artificial load, after the necessary connections have

been made, as shown by the diagram at C in Fig. 304. The diagram at D illustrates the case when the meter is to be tested on the load of the installation. The three-wire test terminals may be used in a similar manner. Fig. 305 is a diagram giving the actual connections between the test terminals and the terminals of this company's two-wire meter. The shunt wire from the + main to the test terminal, as in the diagram, must be of sufficient size to carry the whole testing current, as it will be seen, on reference to diagram C, Fig. 304, that this current passes through the shunt connection when the meter is under test on the artificial load.

Aron Portable Meter.—For taking time tests a portable standard meter is very useful, such as the Aron portable type, illustrated in Fig. 306. It

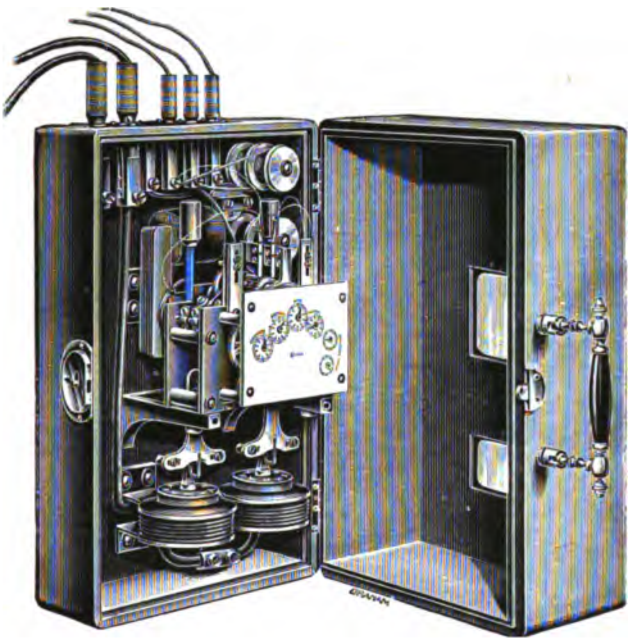

FIG. 306.

differs in a few details from the ordinary meter. The pendulums are balanced by counterweights, and controlled by flat springs which oscillate with the pendulums. One end of each spring is fixed to the pendulum rod, and the other end is attached to a support on the clock frame. These flat springs, which are also being introduced into the ordinary house-service meter, enable a much higher oscillation difference per hour to be obtained than in the ordinary type with gravity-controlled pendulums, in which it amounts to about 3000. The sensitiveness of the meter is thus largely increased. The portable type may be placed almost in any position without producing any adverse result in its registrations, the variation not exceeding $2\frac{1}{2}$ per cent. The slight inequalities in level usually found in practice will, therefore, not affect its accuracy. These instruments are generally provided with two shunt circuits to enable them to be used on two different voltages. They

can be arranged with four different pressure circuits, and for both alternating and direct current up to 400 amperes.

Thomson Portable Meter.—For tram-car testing under running conditions, and for other classes of work requiring a portable instrument, the British Thomson-Houston Company use their meter illustrated in Fig. 307.

FIG. 307.

The meter is suspended within the case by metallic springs, which absorb the jars and vibrations. For general car-testing the 25-ampere size is mostly used.

In making a test with a standard meter the same care must be taken as regards the connections of the pressure circuits of the meter under test and the standard as with a wattmeter, or ammeter and voltmeter. These pressure circuits must be so connected together in parallel across the mains, that the currents they take do not flow in the main circuit of either instrument.

APPENDIX.

Percentage Errors of Continuous Current Three-wire Energy Motor Meters (see page 26).

Table A.—Armature circuit of meter connected across the outer conductors of the three-wire system,—i.e. *energised by the total three-wire voltage.*

Difference of Pressure between the Two Sides expressed as Percentage of the Total Three-wire Voltage.	Percentage Error.		
	10 per cent. Out-of-Balance Current.	15 per cent. Out-of-Balance Current.	20 per cent. Out-of-Balance Current.
0	0	0	0
1	0·053	0·081	0·111
2½	0·132	0·203	0·278
5	0·264	0·407	0·559
10	0·529	0·817	1·123
15	0·796	1·229	1·695
20	1·064	1·648	2·272

Note.—The meter reads high.

Table B.—Armature circuit of meter connected between the *neutral* main and *one* of the two *outer* conductors, and *energised by the greater of the two voltages.*

Difference of Pressure between the Two Sides expressed as Percentage of the Total Three-wire Voltage.	Percentage Error.		
	10 per cent. Out-of-Balance Current.	15 per cent. Out-of-Balance Current.	20 per cent. Out-of-Balance Current.
0	0	0	0
1	1·053	1·090	1·112
2½	2·635	2·708	2·785
5	5·277	5·427	5·586
10	10·582	10·899	11·236
15	15·915	16·415	16·949
20	21·276	21·978	22·727

Note.—The meter reads high.

Table C.—Armature circuit of meter connected between the *neutral* main and *one* of the two *outer* conductors, and *energised by the smaller of the two voltages*.

Difference of Pressure between the Two Sides expressed as Percentage of the Total Three-wire Voltage.	Percentage Error.		
	10 per cent. Out-of-Balance Current.	15 per cent. Out-of-Balance Current.	20 per cent. Out-of-Balance Current.
0	0	0	0
·1	0·948	0·920	0·889
2½	2·371	2·308	2·229
5	4·749	4·613	4·469
10	9·523	9·264	8·988
15	14·323	13·953	13·559
20	19·149	18·681	18·181

Note.—The meter reads low.

The above tables are based on the article "Behaviour of Continuous Current Three-wire Energy Motor Meters" on page 26, Chapter II., from which they can be readily verified.

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